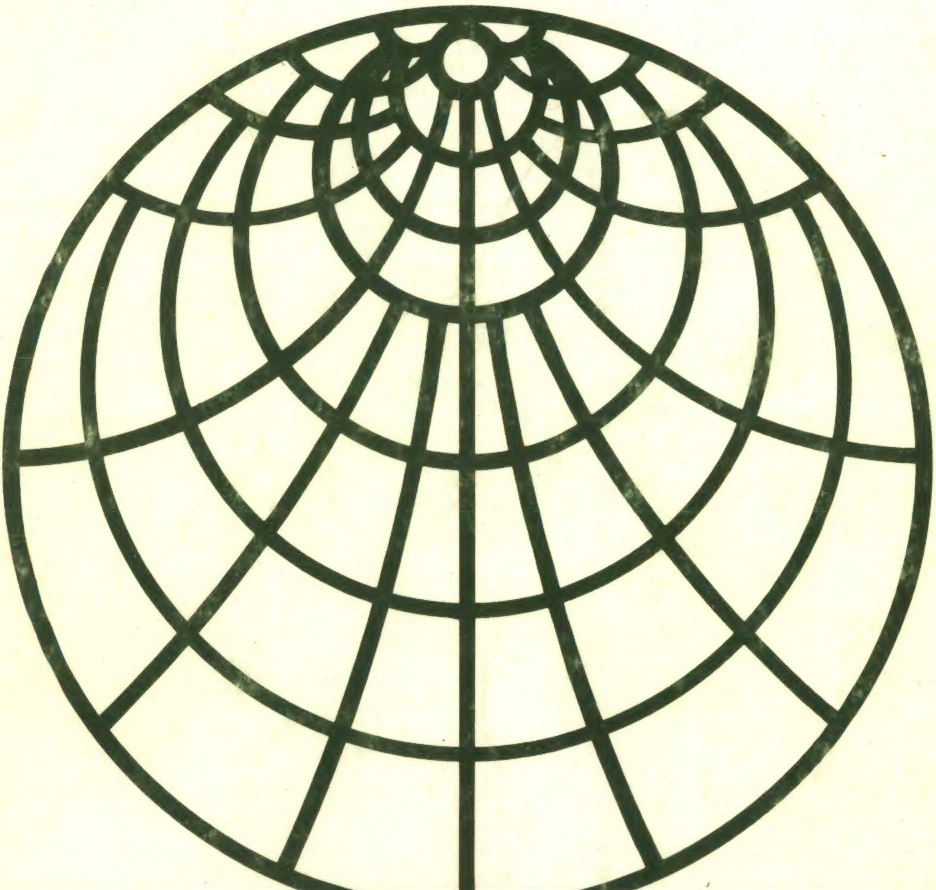
# rf
## semiconductors



MOTOROLA
Semiconductors

# MOTOROLA
# RF DATA MANUAL

Prepared by
Technical Information Center

Motorola's leadership position of RF power, small-signal transistors and hybrid amplifiers is by research and new product development coupled with a complete in-house manufacturing capability including silicon growing, epitaxy, wafer processing, assembly, packaging and testing.

Motorola is dedicated to supplying RF semiconductors with high quality and effective pricing, as well as the data and applications information necessary for the design of high-frequency equipment.

Motorola's RF product range includes power transistors for operation from 2 MHz to 1 GHz; small-signal transistors with $f_T$ values up to 6 GHz; linear hybrid amplifier modules for CATV/MATV and general purpose applications; power hybrid amplifier modules for VHF and UHF FM communications equipment.

The information in this book has been carefully checked and is believed to be reliable; however, no responsibility is assumed for inaccuracies. Furthermore, this information does not convey to the purchaser of microelectronic devices any license under the patent rights of the manufacturer.

First Edition

Printed in Italy

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* Data sheet not available; consult your Motorola sales representative for details.

S — Secondary device; not recommended for new design.

TBA — To be announced. Contact your Motorola sales representative for information.

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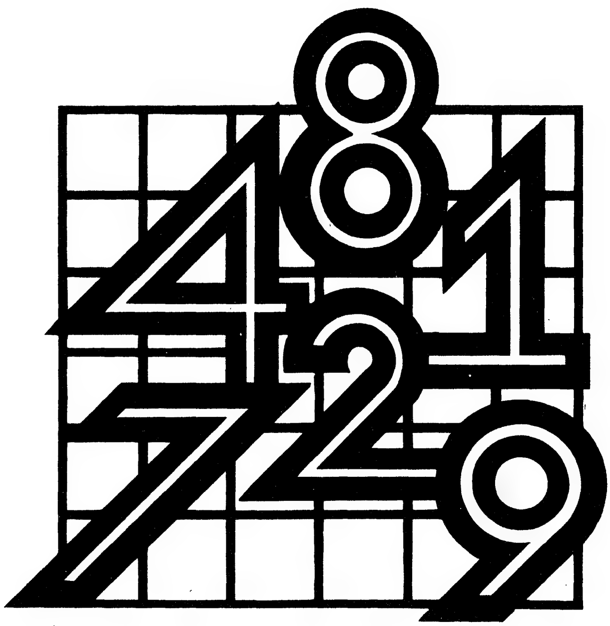
*Data sheet not available; consult your Motorola sales representative for details.

S — Secondary device; not recommended for new design.

TBA — To be announced. Contact your Motorola sales representative for information.

# SELECTION GUIDE AND CROSS REFERENCE

# CHAPTER 1



# RF POWER TRANSISTORS AND MODULES

## High Frequency, Low Voltage Amplifier Transistors/Modules

The transistors listed in this table are specified for operation in RF Power amplifiers and are listed by specific application at a given test frequency. Arrangement within each application group is in the order of increasing output power. Modulation type is given in each application heading.

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **2-30 MHz, SSB TRANSISTORS** | | | | | |
| MRF476 | 0.1 | 3.0 PEP | 15 | 12.5 | TO-220 |
| 2N6367 | 0.36 | 9.0 PEP | 14 | 12.5 | 211-07 |
| MRF475 | 1.2 | 12 PEP | 10 | 13.6 | TO-220 |
| MRF432* | 0.125 | 12.5 PEP | 20 | 12.5 | 211-07 |
| MRF433* | 0.125 | 12.5 PEP | 20 | 12.5 | 211-07 |
| MRF406 | 1.25 | 20 PEP | 12 | 12.5 | 211-07 |
| MRF460 | 2.5 | 40 PEP | 12 | 12.5 | 211-10 |
| MRF421 | 10 | 100 PEP | 10 | 12.5 | 211-08 |

*PNP/NPN Complements for Complementary Symmetry Driver, See EB-32.
For Matched Pairs, Order MK433.

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **14-30 MHz, CB/AMATEUR TRANSISTORS** | | | | | |
| MRF8003 | 0.025 | 0.5 | 13 | 12.5 | TO-39 |
| MRF8004 | 0.35 | 3.5 | 10 | 12.5 | TO-39 |
| MRF449 | 0.30 | 30 | 10 | 13.6 | 211-07 |
| MRF449A | 0.30 | 30 | 10 | 13.6 | 145A-09 |
| MRF450 | 4.0 | 50 | 11 | 13.6 | 211-07 |
| MRF450A | 4.0 | 50 | 11 | 13.6 | 145A-09 |
| MRF453 | 4.8 | 60 | 11 | 12.5 | 211-10 |
| MRF453A | 4.8 | 60 | 11 | 12.5 | 145A-10 |
| MRF455 | 4.8 | 60 | 11 | 12.5 | 211-07 |
| MRF455A | 4.8 | 60 | 11 | 12.5 | 145A-09 |
| MRF454 | 5.0 | 80 | 12 | 12.5 | 211-11 |
| MRF454A | 5.0 | 80 | 12 | 12.5 | 145A-10 |
| **27-50 MHz, LOW-BAND FM TRANSISTORS** | | | | | |
| MRF402 | 0.1 | 1.0 | 10 | 12.5 | TO-39 |
| 2N5847 | 0.8 | 8.0 | 10 | 12.5 | 145A-09 |
| 2N5848 | 3.22 | 20 | 8.0 | 12.5 | 145A-09 |
| 2N5849 | 7.14 | 40 | 7.5 | 12.5 | 145A-10 |
| MRF490 | 5.0 | 50 | 10 | 12.5 | 211-11 |
| MRF490A | 5.0 | 50 | 10 | 12.5 | 145A-10 |
| MRF492 | 7.0 | 70 | 10 | 12.5 | 211-11 |
| MRF492A | 7.0 | 70 | 10 | 12.5 | 145A-10 |
| **40-100 MHz, MIDBAND FM TRANSISTORS** | | | | | |
| MRF229** | 0.15 | 1.5 | 10 | 12.5 | TO-39 |
| MRF230 | 0.15 | 1.5 | 10 | 12.5 | TO-39 |
| MRF231 | 0.15 | 3.5 | 10 | 12.5 | 145A-09 |
| MRF232 | 0.95 | 7.5 | 9.0 | 12.5 | 145A-09 |
| MRF233 | 1.7 | 15 | 9.5 | 12.5 | 145A-09 |
| MRF234 | 2.5 | 25 | 10 | 12.5 | 145A-09 |

**Grounded Emitter TO-39 Package.

# RF POWER TRANSISTORS AND MODULES (continued)

## High Frequency, Low Voltage Amplifier Transistors/Modules (continued)

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **156-162 MHz, VHF MARINE RADIO FM TRANSISTORS/MODULES** | | | | | |
| MRF237* | 0.25 | 4.0 | 12 | 12.5 | TO-39 |
| MRF238 | 3.75 | 30 | 9.0 | 13.6 | 145A-09 |
| MHW603 | 0.20 | 30 | 21.7 | 13.6 | 297-02 |

*Grounded Emitter TO-39 Package. See EB-29.

**130-175 MHz, HIGH-BAND/VHF FM TRANSISTORS**

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| MRF604 | 0.1 | 1.0 | 10 | 12.5 | TO-46 |
| 2N4427 | 0.1 | 1.0 | 10 | 12 | TO-39 |
| MRF607 | 0.1 | 1.75 | 12.5 | 12.5 | TO-39 |
| 2N6255 | 0.5 | 3.0 | 7.8 | 12.5 | TO-39 |
| 2N5589 | 0.44 | 3.0 | 8.2 | 13.6 | 144B-05 |
| MRF237* | 0.25 | 4.0 | 12 | 12.5 | TO-39 |
| 2N6080 | 0.25 | 4.0 | 12 | 12.5 | 145A-09 |
| 2N5590 | 3.0 | 10 | 5.2 | 13.6 | 145A-09 |
| MRF212 | 1.25 | 10 | 9.0 | 12.5 | 145A-09 |
| 2N6081 | 3.3 | 15 | 6.3 | 12.5 | 145A-09 |
| MRF221 | 3.3 | 15 | 6.3 | 12.5 | 211-07 |
| MRF215** | 0.33 | 20 | 8.2 | 12.5 | 316-01 |
| 2N5591 | 9.0 | 25 | 4.4 | 13.6 | 145A-09 |
| 2N6082 | 6.0 | 25 | 6.2 | 12.5 | 145A-09 |
| MRF222 | 6.0 | 25 | 6.2 | 12.5 | 211-07 |
| 2N6083 | 8.1 | 30 | 5.7 | 12.5 | 145A-09 |
| MRF223 | 8.1 | 30 | 5.7 | 12.5 | 211-07 |
| 2N6084 | 14.3 | 40 | 4.5 | 12.5 | 145A-09 |
| MRF224 | 14.3 | 40 | 4.5 | 12.5 | 211-07 |
| MRF216** | 8.5 | 40 | 6.7 | 12.5 | 316-01 |
| MRF243** | 12.0 | 60 | 7.0 | 12.5 | 316-01 |
| MRF245** | 18.2 | 80 | 6.4 | 12.5 | 316-01 |

*Grounded Emitter TO-39 Package. See EB-29.
**Controlled "Q" Transistor. See EB-19.

**146-175 MHz, HIGH-BAND/VHF FM MODULES**

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| MHW601 | 0.1 | 13 | 21 | 12.5 | 297-02 |
| MHW602 | 0.16 | 20 | 21 | 12.5 | 297-02 |
| MHW603 | 0.2 | 30 | 21.7 | 13.6 | 297-02 |

NOTE: See EB-23 for Applications Information.

**220 MHz, CITIZENS BAND FM TRANSISTORS**

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| MRF207 | 0.15 | 1.0 | 8.2 | 12.5 | TO-39 |
| MRF225 | 0.18 | 1.5 | 9.0 | 12.5 | TO-39 |
| MRF227* | 0.13 | 3.0 | 13.5 | 12.5 | TO-39 |
| MRF208 | 0.1 | 10 | 10 | 12.5 | 145A-09 |
| MRF226 | 1.6 | 13 | 9.0 | 12.5 | 145A-09 |
| MRF209 | 9.1 | 25 | 4.4 | 12.5 | 145A-09 |

*Grounded Emitter TO-39 Package. See EB-29.

# RF POWER TRANSISTORS AND MODULES (continued)

## High Frequency, Low Voltage Amplifier Transistors/Modules (continued)

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **407-512 MHz, UHF FM TRANSISTORS** | | | | | |
| 2N6256 | 0.05 | 0.5 | 10 | 12.5 | 249-05 |
| MRF626 | 0.05 | 0.5 | 10 | 12.5 | 305-01 |
| MRF627 | 0.05 | 0.5 | 10 | 12.5 | 305A-01 |
| MRF628 | 0.05 | 0.5 | 10 | 12.5 | 249-05 |
| MRF515 | 0.12 | 0.75 | 8.0 | 12.5 | TO-39 |
| 2N3948 | 0.25 | 1.0 | 6.0 | 13.6 | TO-39 |
| 2N5644 | 0.20 | 1.0 | 7.0 | 12.5 | 145A-09 |
| MRF629* | 0.32 | 2.0 | 8.0 | 12.5 | TO-39 |
| 2N5944 | 0.25 | 2.0 | 9.0 | 12.5 | 244-04 |
| 2N5945 | 0.64 | 4.0 | 8.0 | 12.5 | 244-04 |
| 2N5946 | 2.5 | 10 | 6.0 | 12.5 | 244-04 |
| MRF641** | 3.75 | 15 | 6.0 | 12.5 | 316-01 |
| MRF644** | 5.9 | 25 | 6.2 | 12.5 | 316-01 |
| MRF646** | 13.3 | 40 | 4.8 | 12.5 | 316-01 |
| MRF648** | 22 | 60 | 4.4 | 12.5 | 316-01 |

*Grounded Emitter TO-39 Package. Case 79-03.
**Controlled "Q" Transistor. See EB-19.

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | f MHz | $G_{PE}$ Power Gain dB Min | $V_{DC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|---|
| **407-512 MHz, UHF FM MODULES** | | | | | | |
| MHW401-1 | 0.047 | 1.5 | 400-440 | 15 | 7.5 | 301-01 |
| MHW401-2 | 0.047 | 1.5 | 440-470 | 15 | 7.5 | 301-01 |
| MHW401-3 | 0.047 | 1.5 | 470-512 | 15 | 7.5 | 301-01 |
| MHW709-1 | 0.10 | 7.5 | 400-440 | 18.8 | 12.5 | 700-01 |
| MHW709-2 | 0.10 | 7.5 | 440-470 | 18.8 | 12.5 | 700-01 |
| MHW709-3 | 0.10 | 7.5 | 470-512 | 18.8 | 12.5 | 700-01 |
| MHW710-1 | 0.15 | 13 | 400-440 | 19.4 | 12.5 | 700-01 |
| MHW710-2 | 0.15 | 13 | 440-470 | 19.4 | 12.5 | 700-01 |
| MHW710-3 | 0.15 | 13 | 470-512 | 19.4 | 12.5 | 700-01 |

NOTE: See EB-8 for Applications Information.

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **806-947 MHz, UHF FM TRANSISTORS** | | | | | |
| MRF816 | 0.075 | 0.75 | 10 | 12.5 | 249-05 |
| MRF838 | 0.22 | 1.0 | 6.5 | 12.5 | 305A-01 |
| MRF838A | 0.22 | 1.0 | 6.5 | 12.5 | 305A-01 |
| MRF817 | 0.59 | 2.5 | 6.2 | 13.6 | 244-04 |
| MRF840 | 1.1 | 8.0 | 8.0 | 12.5 | 319-01 |
| MRF842 | 5.0 | 20 | 6.0 | 12.5 | 319-01 |
| MRF844† | 8.1 | 30 | 5.7 | 12.5 | 319-01 |
| MRF846† | 10 | 40 | 6.0 | 12.5 | 319-01 |

†To Be Introduced.

# RF POWER TRANSISTORS AND MODULES (continued)

## High Frequency, High Voltage, Power Amplifier Transistors

The transistors listed in this table are specified for operation in RF Power amplifiers and are listed by specific application at a given test frequency. Arrangement within each application group is in the order of increasing output power. Modulation type is given in each application heading.

| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **2-30 MHz, SSB TRANSISTORS** | | | | | |
| 2N6370 | 0.62 | 10 PEP | 12 | 28 | 211-07 |
| MRF432 | 0.125 | 12.5 PEP | 20 | 12.5 | 211-07 |
| MRF433 | 0.125 | 12.5 PEP | 20 | 12.5 | 211-07 |
| 2N5070 | 1.25 | 25 PEP | 13 | 28 | TO-60 |
| MRF401 | 1.25 | 25 PEP | 13 | 28 | 145A-09 |
| MRF427A | 1.56 | 25 PEP | 12 | 50 | 145A-10 |
| 2N5941 | 2.0 | 40 PEP | 13 | 28 | 211-07 |
| MRF463 | 2.53 | 80 PEP | 15 | 28 | 211-08 |
| MRF464 | 2.53 | 80 PEP | 15 | 28 | 211-11 |
| MRF464A | 2.53 | 80 PEP | 15 | 28 | 145A-10 |
| MRF422 | 15 | 150 PEP | 10 | 28 | 211-08 |
| MRF428 | 7.5 | 150 PEP | 13 | 50 | 211-08 |
| MRF428A | 7.5 | 150 PEP | 13 | 50 | 307-01 |
| **106-175 MHz, VHF AM TRANSISTORS** | | | | | |
| 2N3866 | 0.1 | 1.0 | 10 | 28 | TO-39 |
| 2N3553 | 0.25 | 2.5 | 10 | 28 | TO-39 |
| 2N5641 | 1.0 | 7.0 | 8.4 | 28 | 144B-05 |
| 2N5642 | 3.0 | 20 | 8.2 | 28 | 145A-09 |
| MRF314 | 3.0 | 30 | 10 | 28 | 211-07 |
| MRF314A | 3.0 | 30 | 10 | 28 | 145A-09 |
| 2N5643 | 6.9 | 40 | 7.6 | 28 | 145A-09 |
| MRF315 | 5.7 | 45 | 9.0 | 28 | 211-07 |
| MRF315A | 5.7 | 45 | 9.0 | 28 | 145A-09 |
| MRF316* | 8.0 | 80 | 10 | 28 | 316-01 |
| MRF317* | 12.5 | 100 | 9.0 | 28 | 316-01 |

*Controlled "Q" Transistor. See EB-19

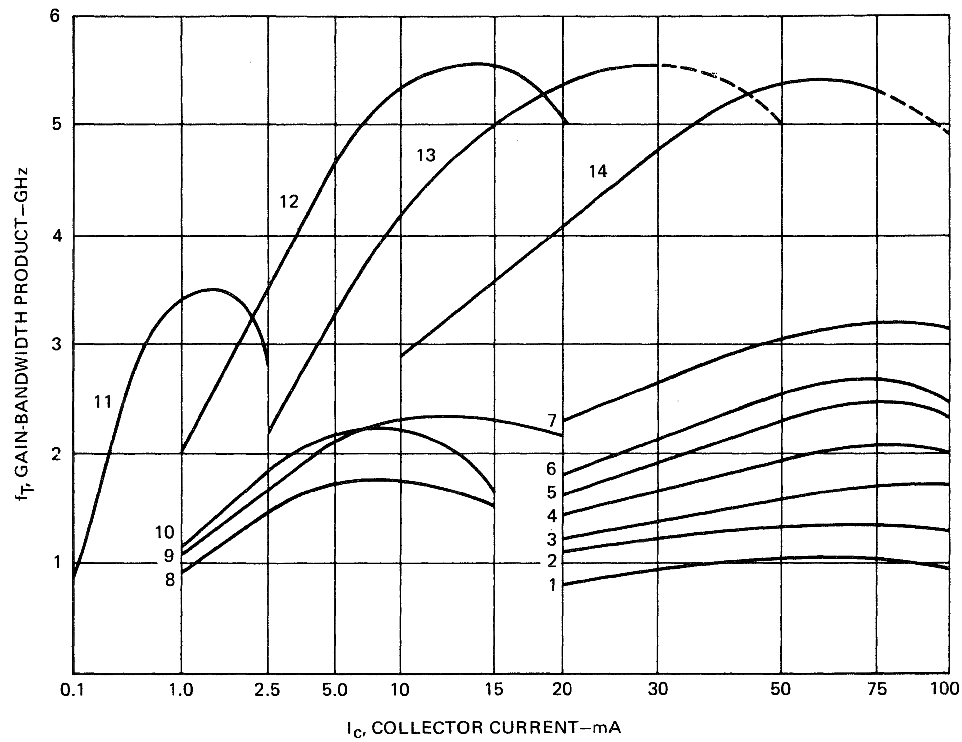
| Device Type | $P_{in}$ Input Power Watts | $P_{out}$ Output Power Watts | $G_{PE}$ Power Gain dB Min | $V_{CC}$ Supply Voltage Volts | Package |
|---|---|---|---|---|---|
| **225-400 MHz, UHF AM TRANSISTORS** | | | | | |
| MRF525 | 0.001 | 0.02 | 13 | 26 | TO-39† |
| 2N3866 | 0.1 | 1.0 | 10 | 28 | TO-39 |
| MRF313 | 0.25 | 1.0 | 16 (typ) | 28 | 305-01 |
| MRF313A | 0.25 | 1.0 | 16 (typ) | 28 | 305A-01 |
| MRF5174 | 0.125 | 2.0 | 12 | 28 | 244-04 |
| MRF321* | 0.62 | 10 | 12 | 28 | 244-04 |
| MRF323* | 2.0 | 20 | 10 | 28 | 244-04 |
| MRF5177 | 7.5 | 30 | 6.0 | 28 | 215-02 |
| MRF5177A | 7.5 | 30 | 6.0 | 28 | 145A-09 |
| MRF325** | 4.3 | 30 | 8.5 | 28 | 316-01 |
| MRF326 | 8.0 | 40 | 9.0 | 28 | 316-01 |
| 2N6439* | 9.5 | 60 | 8.0 | 28 | 316-01 |
| MRF327* | 14.8 | 80 | 7.3 | 28 | 316-01 |

†Grounded Emitter TO-39, Case 79-03.
*Gold Metallization, Double Matched Controlled "Q" Transistor. See EB-26, EB-19.
**Controlled "Q" Transistor. See EB-19.

# SMALL-SIGNAL RF TRANSISTORS

## Typical Gain-Bandwidth Product versus Collector Current

Motorola small-signal and medium power RF transistors with gain-bandwidth products from 1 GHz to 6 GHz operate with currents from 0.25 mA to over 100 mA. The following chart combined with the tables of package options enables the circuit designer to select the optimum device from Motorola's wide range of transistor/package combinations.




| | |
|---|---|
| 1 | 2N3866, 2N3866A, MM8000 |
| 2 | 2N5160, MM4018, PNP |
| 3 | 2N3948, 2N4427, MRF207 |
| 4 | 2N5109, 2N5943, MM8001, MM8002 |
| 5 | 2N5583, PNP |
| 6 | 2N5836, 2N5837 |
| 7 | MRF511, MRF517, MRF525 |
| 8 | 2N2857, 2N3839, 2N5179, MRF501, MRF502 |
| 9 | 2N6304, 2N6305, BFW92, BFX89, BFY90 |
| 10 | 2N4957, 2N4958, 2N4959, PNP |
| 11 | MMBR931, MRF931 |
| 12 | 2N6603, BFR90, MMBR901, MMBR920, MRF901, MRF902, MRF904 |
| 13 | 2N6604, BFR91, MMBR930, MRF911, MRF912, MRF914 |
| 14 | BFR96 |

# SMALL-SIGNAL RF TRANSISTORS (continued)

## UHF and Microwave Oscillators

The transistors listed below are for UHF and microwave oscillator applications as initial signal sources or as output stages of limited range transmitters. Devices are listed in order of increasing test frequency.

| Device Type | Test Conditions f MHz | Test Conditions $V_{CC}$ Volts | $P_{out}$ mW Min | $f_T$ MHz Min | Package |
|---|---|---|---|---|---|
| 2N5179 | 500 | 10 | 20 | 900 | TO-72 |
| 2N2857 | 500 | 10 | 30 | 1000 | TO-72 |
| 2N3839 | 500 | 6.0 | 30 | 1000 | TO-72 |
| MM8009 | 1680 | 20 | 200 | 1000 | TO-39 |
| 2N5108 | 1680 | 20 | 300 | 1200 | TO-39 |
| MRF905 | 1680 | 20 | 500* | 2200* | TO-46 |
| 2N3866 | 400 | 15 | 1000 | 500 | TO-39 |

*Typical

## Low-Noise Transistors

The low-noise devices listed are produced with carefully controlled $r_b'$ and $f_T$ to optimize device noise performance. Devices listed in the matrix are classified according to noise figure performance versus frequency.

| NF dB | Frequency MHz 60 | 100 | 200 | 450 | 1000 | 2000 | Polarity |
|---|---|---|---|---|---|---|---|
| 1.5 | 2N5829 | 2N5829 | | | | | PNP |
| | 2N5031 | 2N5031 | MRF904 | | | | NPN |
| 2.0 | 2N4957 | 2N4957 | 2N5829 | | | | PNP |
| | 2N5032 | 2N5032 | 2N5031 | MRF904 | MRF901 | | NPN |
| 2.5 | 2N4958 | 2N4958 | 2N4957 | 2N5829 | | | PNP |
| | 2N5032 | 2N5032 | 2N5032 | 2N5031 | MRF901 | | NPN |
| | | | | | 2N6603 | | NPN |
| 3.0 | 2N4959 | 2N4959 | 2N4958 | 2N4957 | 2N5829 | | PNP |
| | 2N2857 | 2N2857 | 2N5032 | 3N5032 | MRF901 | MRF902 | NPN |
| | | | | | 2N6604 | | NPN |
| 3.5 | 2N4959 | 2N4959 | 2N4959 | 2N4958 | 2N4957 | | PNP |
| | 2N5179 | 2N5179 | 2N2857 | 3N5032 | 2N5031 | MRF901 | NPN |
| 4.0 | 2N4959 | 2N4959 | 2N4959 | 2N4959 | 2N4958 | | PNP |
| | 2N5179 | 2N5179 | 2N5179 | 2N2857 | 2N5031 | | NPN |
| 4.5 | 2N4959 | 2N4959 | 2N4959 | 2N4959 | 2N4959 | | PNP |
| | 2N5179 | 2N5179 | 2N5179 | 2N2857 | 2N5032 | | NPN |

# SMALL-SIGNAL RF TRANSISTORS (continued)

## High Speed Switches

The transistors listed below are for use as high-frequency current-mode switches. They are also suitable for RF amplifier and oscillator applications. The devices are listed in ascending order of collector current.

| Device Type | Test Conditions $I_C/V_{CE}$ mA/Volts | $f_T$ MHz Min | $r_b'C_c$ Max | Package |
|---|---|---|---|---|
| MD4957 | 2.0/10 | 1000 | 20 | TO-78 |
| 2N3959 | 10/10 | 1300 | 25 | TO-18 |
| 2N3960 | 10/10 | 1600 | 40 | TO-18 |
| 2N5835 | 10/6.0 | 2500 | 5.0** | TO-72 |
| MM4049* | 20/5.0 | 4000 | 15 | TO-72 |
| MRF914 | 20/10 | 4500** | – | TO-72 |
| 2N5842 | 25/4.0 | 1700 | 40 | TO-72 |
| 2N5841 | 25/4.0 | 2200 | 25 | TO-72 |
| MRF531 | 50/25 | 500 | – | TO-39 |
| MRF532* | 50/25 | 500 | – | TO-39 |
| 2N5583* | 50/10 | 1000 | 8.0** | TO-39 |
| 2N5836 | 50/6.0 | 2000 | 6.0** | TO-46 |
| 2N5837 | 100/3.0 | 1700 | 6.0** | TO-46 |

*PNP **Typ

## CATV, MATV, and Class A Linear Transistors

The devices listed below are excellent for Class A linear CATV/MATV applications. The devices are listed according to increasing Current-Gain ($f_T$). More information concerning the device for your specific linear design needs can be obtained through your local Motorola Sales Office or Motorola distributor.

| Device Type | Nominal Test Conditions $V_{CE}/I_C$ Volts/mA | $f_T$ MHz Min | Noise Figure Max/Freq. MHz | Distortion Specifications 2nd Order IMD | 3rd Order IMD | 12 Ch. Cross-Mod. | Output Level dbMV | Package |
|---|---|---|---|---|---|---|---|---|
| MRF501 | 6/5 | 600 | 4.5*/200 | | | | | TO-72 |
| MRF502 | 6/5 | 800 | 4.0*/200 | | | | | TO-72 |
| 2N5179 | 6/5 | 900 | 4.5/200 | | | | | TO-72 |
| BFY90 | 5/2 | 1000 | 5.0/500 | | | | | TO-72 |
| BFW92 | 5/2 | 1000 | 4.0/500 | | | | | 302A-01 |
| 2N6305 | 5/10 | 1200 | 5.5/450 | | | | | TO-72 |
| BFX89 | 5/25 | 1200 | 6.5/500 | | | | | TO-72 |
| 2N5109 | 15/50 | 1200 | 3.0*/200 | | | | | TO-39 |
| 2N5943 | 15/50 | 1200 | 3.4/200 | -50 | | -42 | +50 | TO-39 |
| 2N6304 | 5/10 | 1400 | 4.5/450 | | | | | TO-72 |
| MRF511 | 20/80 | 1500 | 7.3*/200 | -50 | -65 | -57 | +50 | 144D-04 |
| MRF517 | 15/60 | 2200 | 7.5/300 | -60 | -72 | -57 | +45 | TO-39 |
| BFR90 | 10/14 | 5000* | 2.4*/500 | | | | | 302A-01 |
| BFR91 | 5/35 | 5000* | 1.9*/500 | | | | | 302A-01 |
| BFR96 | 10/50 | 5000* | 3.3*/500 | | | | | 302A-01 |

*Typ

## Hybrid Amplifier Modules

The Hybrid Modules listed are specified for amplifier applications in CATV distribution equipment, but are applicable wherever broadband (HF/VHF) low distortion, low-noise amplification is required. These modules are also specified as wideband amplifiers for use in communications/ instrumentation equipment operating in bands from 1 MHz to 400 MHz.

**CATV HYBRID MODULES**

| Device Type | Gain 40-300 MHz db Min/Typ | Maximum Distortion Specifications Output Level dBmV | 2nd Order Test Note 1 dB | 35 Channel Triple Beat dB | 35 Channel Cross-Mod. dB | Noise Figure @ 300 MHz dB |
|---|---|---|---|---|---|---|
| MHW1121 | 11.6/12.0 | +50 | −68 | −51 | −51 | 7.0 |
| MHW1122 | 11.6/12.0 | +50 | −70 | −56 | −56 | 8.0 |
| MHW1171 | 16.6/17 | +50 | −68 | −51 | −51 | 7.0 |
| MHW1172 | 16.6/17 | +50 | −70 | −56 | −56 | 8.0 |
| MHW1182* | 18.0/18.5 | +50 | −72 | −80† | −57†† | 7.0 |
| MHW1221 | 21.4/22 | +50 | −64 | −51 | −51 | 6.0 |
| MHW1222 | 21.4/22 | +50 | −66 | −55 | −56 | 7.0 |
| MHW1341 | 33/34 | +48 | −68 | −55 | −55 | 7.0 |
| MHW1342 | 33/34 | +48 | −70 | −57 | −57 | 7.0 |
| MHW1343** | 33/34 | +48 | −64 | −55 | −55 | 7.0 |

Note 1. Channels (2 and 13) @ R.

*Operating Frequency Range = 5 to 120 MHz.

**Two Section—Accessible Interstage.

†3 Channels Triple Beat

††12 Channels @ $P_{out}$ = +54 dBmV.

**GENERAL-PURPOSE 50 Ω–100 Ω WIDEBAND MODULES**

| Device Type | Frequency Range MHz | Gain dB Min/Typ | Supply Voltage Vdc | Output Level 1 dB Compression mW/f (MHz) | Noise Figure @ 250 MHz dB |
|---|---|---|---|---|---|
| MHW590 | 10-400 | 32.5/34 | 24 | 800/200 | 5.0 |
| MHW591 | 1.0-250 | 35/36.5 | 13.6 | 700/100 | 5.0 |
| MHW592 | 1.0-250 | 34.5/36 | 24 | 900/100 | 5.0 |
| MHW593 | 10-400 | 34/35.5 | 13.6 | 600/200 | 4.5 |

**TO-39 WIDEBAND, 50 Ω MODULES**

| Device Type | Frequency Range MHz | Gain dB Min/Typ | Supply Voltage Vdc | Output Level 1 dB Compression dBm | Noise Figure dB |
|---|---|---|---|---|---|
| MWA110# | DC-400 | 13/14 | 10 | −3.0 | 5 |
| MWA120# | DC-400 | 13/14 | 10 | +6.5 | 7 |

#To Be Introduced.

# SMALL-SIGNAL RF TRANSISTORS (continued)

## Selection By Package

In small-signal RF applications the package style is often determined by the end application or circuit construction technique. To aid the circuit designer in device selection below are listed the Motorola broad range of RF small-signal transistors organized by package.

**TO-39 METAL CAN**

| Device Type | Gain–BW | | Noise Figure | | | Gain | | Maximum Ratings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $f_T$ GHz | $I_C$ mA | NF dB | f MHz | $I_C$ mA | dB Min | f – | $BV_{CEO}$ V | $I_C$ mA | $P_T$ mW-$T_A$ |
| MM8000 | 0.7 | 50 | 2.7 | 200 | 10 | 11.4* | 200 | 30 | 0.4 | 350 $T_C$ |
| MM8001 | 0.9 | 50 | 2.7 | 200 | 10 | 11.4* | 200 | 30 | 0.4 | 350 $T_C$ |
| 2N5109 | 1.2 | 50 | 3.0 | 200 | 10 | 11 | 216 | 20 | 400 | 250 $T_C$ |
| 2N5943 | 1.2 | 50 | 3.4 | 200 | 30 | 11.4* | 200 | 30 | 400 | 100 |
| MRF525 | 2.5 | 50 | 4.0 | 400 | – | 13 | 400 | 35** | 150 | 250 $T_C$ |
| MRF517 | 2.7 | 60 | 7.5 | 300 | 50 | 10* | 300 | 35** | 150 | 250 $T_C$ |

*Typ **$BV_{CBO}$

**TO-72 METAL CAN**

| Device Type | Gain–BW | | Noise Figure | | | Gain | | Maximum Ratings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $f_T$ GHz | $I_C$ mA | NF dB | f MHz | $I_C$ mA | dB Min | f – | $BV_{CEO}$ V | $I_C$ mA | $P_T$ mW-$T_A$ |
| 2N5031 | 1.0 | 5.0 | 2.5 | 450 | 1.0 | 14 | 450 | 10 | 20 | 200 |
| 2N5032 | 1.0 | 5.0 | 3.0 | 450 | 1.0 | 14 | 450 | 10 | 20 | 200 |
| 2N4958* | 1.0 | 2.0 | 3.3 | 450 | 2.0 | 16 | 450 | 30 | 30 | 200 |
| 2N4959* | 1.0 | 2.0 | 3.8 | 450 | 2.0 | 15 | 450 | 30 | 30 | 200 |
| 2N5829 | 1.2 | 2.0 | 2.5 | 450 | 2.0 | 17 | 450 | 30 | 30 | 200 |
| 2N4957* | 1.2 | 2.0 | 3.0 | 450 | 2.0 | 17 | 450 | 30 | 30 | 200 |
| MRF501 | 1.2 | 5.0 | 4.0 | 200 | 1.5 | 15** | 200 | 15 | 50 | 200 |
| MRF502 | 1.2 | 5.0 | 4.0 | 200 | 1.5 | 15** | 200 | 15 | 50 | 200 |
| 2N6305 | 1.2 | 10 | 5.5 | 450 | 2.0 | 12 | 450 | 15 | 50 | 200 |
| BFX89 | 1.2 | 25 | 6.5 | 500 | 2.0 | 19 | 200 | 15 | 50 | 200 |
| BFY90 | 1.4 | 25 | 5.0 | 500 | 2.0 | 21 | 200 | 15 | 50 | 200 |
| 2N5179 | 1.4 | 10 | 4.5 | 200 | 1.5 | 15 | 200 | 12 | 50 | 200 |
| 2N6304 | 1.4 | 10 | 4.5 | 450 | 2.0 | 15 | 450 | 15 | 50 | 200 |
| 2N3839 | 1.6 | 8.0 | 3.9 | 450 | 1.5 | 12.5 | 450 | 15 | 40 | 200 |
| 2N2857 | 1.6 | 8.0 | 4.1 | 450 | 1.5 | 12.5 | 450 | 15 | 40 | 200 |
| MRF904 | 4.0 | 15 | 1.5 | 450 | 5.0 | 16 | 450 | 15 | 30 | 200 |
| MRF914 | 4.5 | 20 | 2.0 | 500 | 5.0 | 15 | 500 | 12 | 40 | 200 |

*PNP **Typ

# SMALL-SIGNAL RF TRANSISTORS (continued)

## Selection By Package (continued)

**PLASTIC – SOE**

| | Gain–BW | | Noise Figure | | | Gain | | Maximum Ratings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Device Type | $f_T$ GHz | $I_C$ mA | NF dB | f MHz | $I_C$ mA | dB Min | f – | $BV_{CEO}$ V | $I_C$ mA | $P_T$ mW-$T_A$ |
| BFW92 | 2.0 | 25 | 2.5 | 500 | 2.0 | 16* | 500 | 5.0 | 50 | 50 |
| MRF931 | 3.0 | 1.0 | 3.8 | 500 | 0.25 | 16* | 500 | 5.0 | 5.0 | 50 |
| MRF901 | 4.5 | 15 | 2.0 | 1000 | 5.0 | 10 | 1000 | 15 | 30 | 375 $T_C$ |
| MRF911 | 5.0 | 30 | 2.5 | 1000 | 5.0 | 12.5* | 1000 | 12 | 40 | 400 $T_C$ |
| BFR90 | 5.0 | 14 | 2.4 | 500 | 2.0 | 18* | 500 | 15 | 30 | 180 |
| BFR91 | 5.0 | 30 | 1.9 | 500 | 2.0 | 16* | 500 | 12 | 35 | 180 |
| BFR96 | 5.0 | 60 | 45 | 500 | 40 | 9.0 | 860 | 15 | 90 | 500 $T_C$ |

*Typ

**CERAMIC – SOE**

| | Gain–BW | | Noise Figure | | | Gain | | Maximum Ratings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Device Type | $f_T$ GHz | $I_C$ mA | NF dB | f MHz | $I_C$ mA | dB Min | f – | $BV_{CEO}$ V | $I_C$ mA | $P_T$ mW-$T_A$ |
| 2N5947 | 1.5 | 75 | 3.8 | 200 | 50 | 10 | 250 | 30 | 400 | 500 $T_C$ |
| MRF511 | 2.1 | 80 | 7.3 | 200 | 50 | 10 | 250 | 25 | 250 | 500 $T_C$ |
| MRF902 | 4.5 | 15 | 2.0 | 1000 | 5.0 | 13* | 1000 | 15 | 30 | 400 $T_C$ |
| 2N6603 | 4.5 | 15 | 2.0 | 1000 | 5.0 | 13* | 1000 | 15 | 30 | 400 $T_C$ |
| MRF912 | 5.0 | 30 | 2.5 | 1000 | 5.0 | 14 | 1000 | 12 | 50 | 500 $T_C$ |
| 2N6604 | 5.0 | 30 | 2.5 | 1000 | 5.0 | 14 | 1000 | 12 | 50 | 500 $T_C$ |

*Typ

**MiniBloc (SOT-23)–Case 318**

| | Gain–BW | | Noise Figure | | | Gain | | Maximum Ratings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Device Type | $f_T$ GHz | $I_C$ mA | NF dB | f MHz | $I_C$ mA | dB Min | f – | $BV_{CEO}$ V | $I_C$ mA | $P_T$ mW-$T_A$ |
| MMBR5179 | 1.5 | 5.0 | 4.0 | 450 | 1.5 | 11 | 450 | 12 | 50 | 200 |
| MMBR4957* | 2.0 | 2.0 | 2.5 | 450 | 2.0 | 14.5 | 450 | 30 | 30 | 200 |
| MMBR5031 | 2.0 | 5.0 | 1.9 | 450 | 1.0 | 13.5 | 450 | 10 | 20 | 200 |
| MMBR2060 | 2.5 | 20 | 2.0 | 500 | 1.5 | 13 | 500 | 14 | 50 | 200 |
| MMBR931 | 3.5 | 1.0 | 2.7 | 500 | 0.5 | 18 | 500 | 5.0 | 5.0 | 50 |
| MMBR901 | 4.0 | 15 | 2.3 | 1000 | 5.0 | 10.5 | 1000 | 15 | 30 | 200 |
| MMBR920 | 5.0 | 14 | 2.4 | 500 | 2.0 | 17 | 500 | 15 | 30 | 200 |
| MMBR930 | 5.5 | 30 | 1.9 | 500 | 2.0 | 15.5 | 500 | 12 | 35 | 200 |

*PNP

# HIGH RELIABILITY RF TRANSISTORS

The listed devices are active per QPL-19500 (Qualified Products List) as of August 22, 1977. Check with your local Motorola Sales Office or franchised Distributor for current qualification status and additions.

| | |
|---|---|
| 2N2857JAN | 2N3960JAN |
| 2N2857JTX | 2N3960JTX |
| 2N2857JTXV | 2N3960JTXV |
| 2N3375JAN | 2N4957JAN |
| 2N3375JTX | 2N4957JTX |
| 2N3375JTXV | 2N4957JTXV |
| 2N3553JAN | 2N5109JAN |
| 2N3553JTX | 2N5109JTX |
| 2N3553JTXV | 2N5109JTXV |
| 2N3866JAN | *2N6603JAN |
| 2N3866JTX | *2N6603JTX |
| 2N3866JTXV | *2N6603JTXV |
| 2N3866AJAN | *2N6604JAN |
| 2N3866AJTX | *2N6604JTX |
| 2N3866AJTXV | *2N6604JTXV |

*Qualification in process.

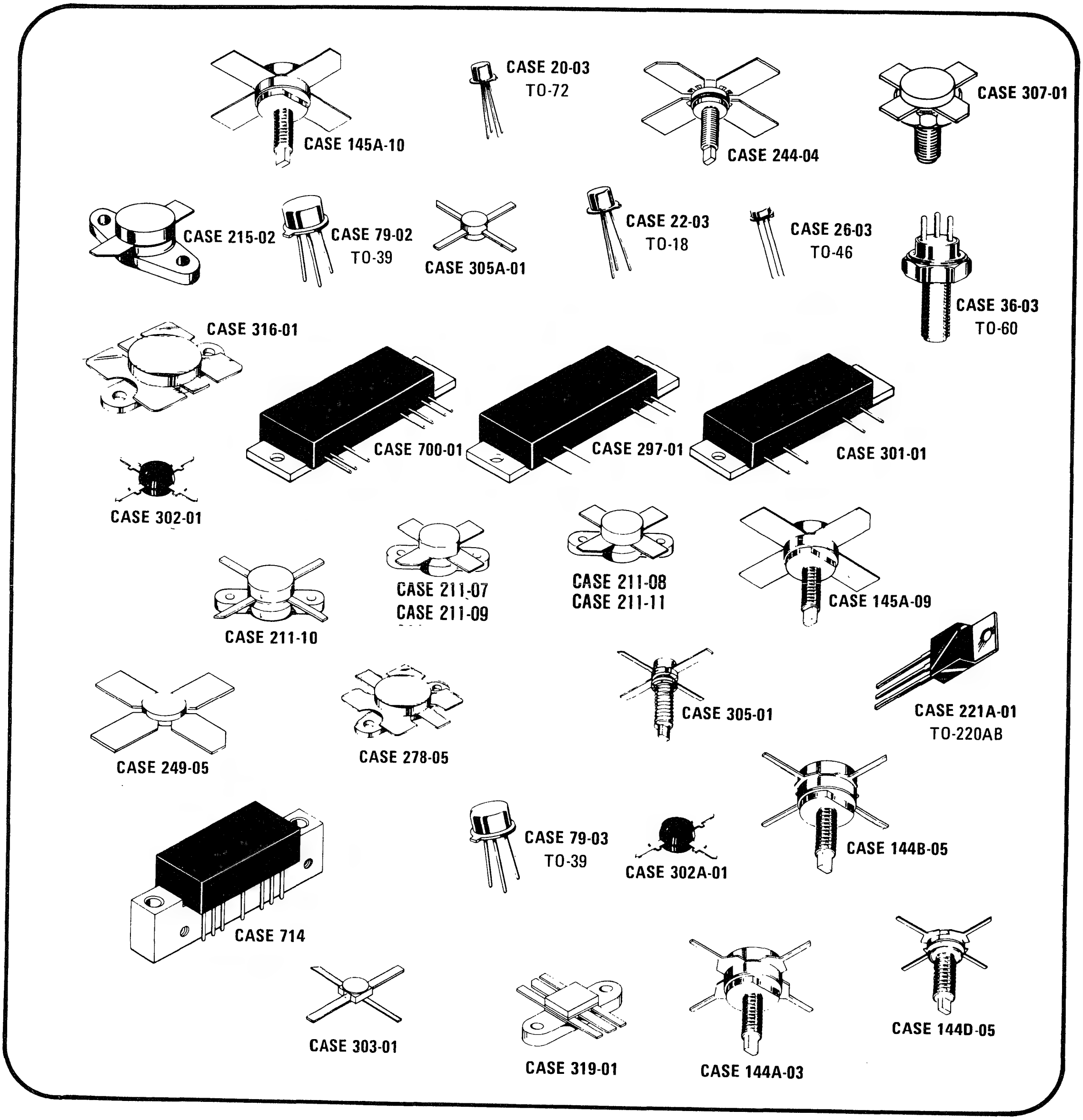
# TRANSISTOR COMPLEMENTS

The transistor complements listed are suitable for most applications requiring NPN and PNP devices of similar RF characteristics. If your applications demands special matching of complementary transistors, please contact your local Motorola Sales Office or Motorola distributors.

| NPN | PNP |
|---|---|
| 2N3866 | 2N5160 |
| 2N3553 | MM4019 |
| 2N2857 | 2N4958 (not true complement but close) |
| 2N3959, 2N3960 | 2N4260, 2N4261 |
| 2N3960JAN | MM4261H |
| 2N3375 | 2N5161 (best match available) |
| 2N5643 | 2N5162 (in SOE needs base stabilization) |
| 2N6080 | 2N6094 |
| 2N6081 | 2N6095 |
| 2N6082 | 2N6096 |
| 2N6084 | 2N6097 |
| MM8023 | 2N5583 |
| MRF904 | MM4049 (best match available) |
| MRF531 | MRF532 |
| MRF433 | MRF432 |

# PACKAGE INFORMATION

## Package Overview



# PACKAGE INFORMATION (continued)

## Standard Stripline Opposed Emitter (SOE) and Flange Mount Packages

| Package | Body O.D. | Number of Leads | Lead Width | Stud Thread | Wrench Flat |
|---|---|---|---|---|---|
| **Stud Mount** | | | | | |
| 144B-04 | 0.380 | 4 | Narrow | 8-32 | Yes |
| 144D-05 | 0.280 | 4 | Narrow | 8-32 | Yes |
| 145A-09 | 0.380 | 4 | Wide | 8-32 | Yes |
| 145A-10 | 0.500 | 4 | Wide | 10-32 | Yes |
| 145C-03 | 0.500 | 2 | Wide | 10-32 | Yes |
| 244-04 | 0.280 | 4 | Wide | 8-32 | Yes |
| 305-01 | 0.200 | 4 | Narrow | 8-32 | Yes |
| 307-01 | 0.550 | 4 | Wide | 1/4--28 | Yes |
| **Flange** | | | | | |
| 211-08 | 0.500 | 4 | Wide | Flange | |
| 211-07 | 0.380 | 4 | Wide | Flange | |
| 211-10 | 0.470 | 4 | Narrow | Flange | |
| 211-11 | 0.490 | 4 | Wide | Flange | |
| 215-02 | 0.380 | 2 | Wide | Flange | |
| 316-01 | 0.500 | 4, CQ | Wide | Flange | |
| 278-05 | 0.380 | 4, CQ | Wide | Flange | |
| 319-01 (CS12) | 0.230 | 4, CQ | Narrow | Flange | |
| **Studless** | | | | | |
| 144C-04 | 0.380 | 4 | Narrow | Studless | |
| 207A-01 | 0.280 | 4 | Narrow | Studless | |
| 249-05 | 0.280 | 4 | Wide | Studless | |
| 305A-01 | 0.200 | 4 | Narrow | Studless | |
| **Small-Signal Plastic** | | | | | |
| 302-01 | 0.188 | 4 | Narrow | Studless | |
| 302A-01 | 0.188 | 3 | Narrow | Studless | |
| **Ceramic** | | | | | |
| 303-01 | 0.100 | 4 | Narrow | Studless | |

# PACKAGE INFORMATION (continued)

## Stud Torque

| Condition | TO-102 6-32 | SOE 8-32 | SOE 10-32 | TO-60 10-32 | SOE 1/4-28 |
|---|---|---|---|---|---|
| For repeated use (inch–lb) | 1.8 | 5.0 | 8.5 | 12 | 35 |
| One time only (inch–lb) | 2.1 | 6.5 | 11.0 | 15 | 35 |

D flat alignment $\pm 5^{\circ}$ from collector lead

## Mounting Hardware

| 6–32 Stud | Part Number |
|---|---|
| Hex Nut | BO9490A006 |
| Lock Washer | B52200F004 |
| Flat Washer | B51567F036 |
| **8–32 Stud** | |
| Hex Nut | B51568F042 |
| Lock Washer | B51566F030 |
| Flat Washer | B51567F038 |
| **10–32 Stud** | |
| Hex Nut | B51568F015 |
| Lock Washer | B51566F020 |
| Flat Washer | B51567F009 |
| **1/4–28 Stud** | |
| Hex Nut | B51568F029 |
| Lock Washer | B51566F011 |
| Flat Washer | B51567F025 |

# MOTOROLA RF CROSS-REFERENCE LIST

This list represents the closest electrical and mechanical Motorola equivalents to most industry RF offerings. Some devices may not be exact electrical replacements; some are in different packages. If the unit does not meet specific requirements, contact your Motorola representative for a custom-designed device specially selected and built to meet your application needs.



| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 2N1491 | | MRF531 |
| 2N2631 | | 2N3553 |
| 2N2857 | 2N2857 | |
| 2N2876 | | 2N3375 |
| 2N2947 | | 2N5641 |
| 2N3118 | | 2N3553 |
| 2N3119 | | MRF531 |
| 2N3137 | 2N3137 | |
| 2N3287 | 2N3287 | |
| 2N3288 | 2N3287 | |
| 2N3289 | 2N3287 | |
| 2N3290 | 2N3287 | |
| 2N3293 | 2N3287 | |
| 2N3296 | | 2N5641 |
| 2N3309A | | 2N3553 |
| 2N3375 | 2N3375 | |
| 2N3478 | | 2N5179 |
| 2N3553 | 2N3553 | |
| 2N3570 | 2N5032 | |
| 2N3571 | | 2N5032 |
| 2N3572 | | 2N5032 |
| 2N3600 | | 2N5179 |
| 2N3632 | 2N3632 | |
| 2N3733 | 2N3632 | |
| 2N3818 | | 2N3632 |
| 2N3839 | 2N3839 | |
| 2N3866 | 2N3866 | |
| 2N3880 | | 2N5032 |
| 2N3925 | | 2N5589 |
| 2N3926 | 2N3926 | |
| 2N3927 | 2N3927 | |
| 2N3948 | 2N3948 | |
| 2N3950 | 2N3950 | |
| 2N3959 | 2N3959 | |
| 2N3960 | 2N3960 | |
| 2N3961 | | 2N5641 |
| 2N4012 | 2N4012 | |
| 2N4040 | 2N5636 | |
| 2N4041 | 2N5635 | |
| 2N4072 | 2N4072 | |
| 2N4073 | 2N4073 | |
| 2N4127 | 2N6081 | |
| 2N4128 | 2N6082 | |
| 2N4130 | 2N4130 | |
| 2N4130 | | MRF463 |
| 2N4192 | | MRF531 |
| 2N4193 | | MRF531 |
| 2N4427 | 2N4427 | |
| 2N4428 | 2N4428 | |
| 2N4440 | 2N4440 | |
| 2N4932 | | 2N3926 |
| 2N4933 | | 2N3927 |
| 2N4957 | 2N4957 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 2N4958 | 2N4958 | |
| 2N5016 | 2N5016 | |
| 2N5031 | 2N5031 | |
| 2N5032 | 2N5032 | |
| 2N5053 | 2N6305 | |
| 2N5054 | 2N6304 | |
| 2N5070 | 2N5070 | |
| 2N5071 | 2N5071 | |
| 2N5090 | 2N5090 | |
| 2N5102 | | 2N5071 |
| 2N5108 | 2N5108 | |
| 2N5109 | 2N5109 | |
| 2N5160 | 2N5160 | |
| 2N5161 | 2N5161 | |
| 2N5162 | 2N5162 | |
| 2N5179 | 2N5179 | |
| 2N5180 | | 2N5179 |
| 2N5262 | | MRF531 |
| 2N5421 | 2N4427 | |
| 2N5422 | MRF606 | |
| 2N5423 | 2N3926 | |
| 2N5424 | 2N3927 | |
| 2N5460 | MRF454 | |
| 2N5583 | 2N5583 | |
| 2N5589 | 2N5589 | |
| 2N5590 | 2N5590 | |
| 2N5591 | 2N5591 | |
| 2N5635 | 2N5635 | |
| 2N5636 | 2N5636 | |
| 2N5637 | 2N5637 | |
| 2N5641 | 2N5641 | |
| 2N5642 | 2N5642 | |
| 2N5643 | 2N5643 | |
| 2N5644 | 2N5644 | |
| 2N5645 | 2N5645 | |
| 2N5646 | 2N5646 | |
| 2N5687 | 2N4427 | |
| 2N5688 | | MRF475 |
| 2N5689 | 2N5847 | |
| 2N5690 | 2N5848 | |
| 2N5691 | | 2N5849 |
| 2N5697 | MRF515 | |
| 2N5698 | 2N5944 | |
| 2N5699 | | 2N5847 |
| 2N5707 | MRF401 | |
| 2N5708 | 2N5941 | |
| 2N5710 | 2N4073 | |
| 2N5711 | 2N5641 | |
| 2N5712 | 2N5642 | |
| 2N5713 | 2N5642 | |
| 2N5714 | 2N5643 | |
| 2N5773 | MRF5174 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 2N5774 | 2N5636 | |
| 2N5775 | MRF5177 | |
| 2N5829 | 2N5829 | |
| 2N5834 | 2N3553 | |
| 2N5835 | 2N5835 | |
| 2N5836 | 2N5836 | |
| 2N5837 | 2N5837 | |
| 2N5841 | 2N5841 | |
| 2N5842 | 2N5842 | |
| 2N5846 | | MRF231 |
| 2N5847 | 2N5847 | |
| 2N5848 | 2N5848 | |
| 2N5849 | 2N5849 | |
| 2N5862 | 2N5862 | |
| 2N5913 | MRF607 | |
| 2N5914 | 2N5944 | |
| 2N5915 | 2N5946 | |
| 2N5916 | MRF5177 | |
| 2N5917 | | MRF5174 |
| 2N5918 | | MRF321 |
| 2N5919A | | MRF323 |
| 2N5941 | 2N5941 | |
| 2N5942 | 2N5942 | |
| 2N5943 | 2N5943 | |
| 2N5944 | 2N5944 | |
| 2N5945 | 2N5945 | |
| 2N5946 | 2N5946 | |
| 2N5947 | 2N5947 | |
| 2N5992 | MRF232 | |
| 2N5993 | MRF234 | |
| 2N5994 | 2N5643 | |
| 2N5995 | MRF212 | |
| 2N5996 | 2N6081 | |
| 2N6080 | 2N6080 | |
| 2N6081 | 2N6081 | |
| 2N6082 | 2N6082 | |
| 2N6083 | 2N6083 | |
| 2N6084 | 2N6084 | |
| 2N6093 | MRF464 | |
| 2N6094 | 2N6094 | |
| 2N6095 | 2N6095 | |
| 2N6096 | 2N6096 | |
| 2N6097 | 2N6097 | |
| 2N6104 | | MRF5177 |
| 2N6105 | | MRF5177A |
| 2N6136 | 2N6136 | |
| 2N6166 | 2N6166 | |
| 2N6197 | 2N3553 | |
| 2N6198 | 2N5641 | |
| 2N6199 | 2N5642 | |
| 2N6200 | 2N5643 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 2N6201 | 2N6166 | |
| 2N6202 | MRF5174 | |
| 2N6203 | MRF5175 | |
| 2N6204 | 2N5637 | |
| 2N6205 | MRF5177 | |
| 2N6255 | 2N6255 | |
| 2N6256 | 2N6256 | |
| 2N6304 | 2N6304 | |
| 2N6305 | 2N6305 | |
| 2N6361 | MRF325 | |
| 2N6362 | 2N6439 | |
| 2N6366 | | MRF475 |
| 2N6367 | MRF433 | |
| 2N6368 | MRF460 | |
| 2N6439 | 2N6439 | |
| 2N6455 | MRF406 | |
| 2N6456 | MRF406 | |
| 2N6457 | MRF460 | |
| 2N6458 | MRF460 | |
| 2N6459 | MRF454 | |
| 2SC319 | 2N4427 | |
| 2SC320 | MRF60 | |
| 2SC567 | 2N5031 | |
| 2SC568 | 2N5031 | |
| 2SC571 | 2N4427 | |
| 2SC572 | 2N3926 | |
| 2SC573 | 2N3927 | |
| 2SC585 | 2N3632 | |
| 2SC597 | 2N3553 | |
| 2SC598 | 2N3926 | |
| 2SC600 | 2N3927 | |
| 2SC628 | MRF225 | |
| 2SC635 | | 2N3632 |
| 2SC636 | | 2N3632 |
| 2SC637 | 2N3926 | |
| 2SC638 | 2N3927 | |
| 2SC651 | | 2N4428 |
| 2SC652 | 2N5943 | |
| 2SC821 | 2N4427 | |
| 2SC822 | MRF607 | |
| 2SC823 | | 2N5943 |
| 2SC824 | | 2N5943 |
| 2SC831 | | 2N3927 |
| 2SC852 | | 2N5943 |
| 2SC890 | | MRF515 |
| 2SC891 | 2N5645 | |
| 2SC892 | 2N5646 | |
| 2SC988 | 2N6304 | |
| 2SC988A | | MRF904 |
| 2SC990 | | 2N5646 |
| 2SC1043 | MRF511 | |
| 2SC1044 | 2N2857 | |
| 2SC1081 | 2N5646 | |
| 2SC1090 | | BFR90 |
| 2SC1119 | | MRF902 |
| 2SC1251 | | MRF511 |
| 2SC1252 | MRF517 | |
| 2SC1254 | 2N2857 | |
| 2SC1256 | 2N6255 | |
| 2SC1257 | 2N5590 | |
| 2SC1258 | 2N6081 | |
| 2SC1259 | | 2N6083 |
| 2SC1260 | 2N6304 | |
| 2SC1275 | 2N6304 | |
| 2SC1297 | | 2N6082 |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 2SC1298 | | 2N6084 |
| 2SC1329 | | MRF234 |
| 2SC1336 | | MRF902 |
| 2SC1365 | | MRF517 |
| 2SC1366 | | MRF517 |
| 2SC1603 | 2N5944 | |
| 2SC1604 | MRF628 | |
| 2SC1605A | MRF226 | |
| 2SC1606 | | MRF327 |
| 2SC1689 | 2N5643 | |
| 2SC1729 | MRF226 | |
| 2SC1804 | | MRF321 |
| 2SC1805 | | MRF323 |
| 2SC1806 | | MRF5177A |
| 2SC1807 | | BFY90 |
| 2SC1808 | | 2N5944 |
| 2SC1946 | | MRF222 |
| 2SC1947 | | 2N3924 |
| 2SC1966 | | 2N5944 |
| 2SC1967 | | 2N5945 |
| 2SC1968 | | MRF641 |
| 2SC1969 | MRF475 | |
| 2SC2040 | MRF511 | |
| 2SC2132 | | MRF646 |
| 3TX620 | 2N5944 | |
| 3TX621 | 2N5944 | |
| 3TX622 | 2N5945 | |
| 3TX820 | 2N5944 | |
| 3TX822 | 2N5945 | |
| 35821B | | MRF902B |
| 35821E | | MRF902 |
| 35822B | | MRF902B |
| 35822E | | MRF902 |
| 35824A | | MRF904 |
| 35825B | | MRF902B |
| 35825E | | MRF902 |
| 40080 | | MRF8003 |
| 40081 | MRF8003 | |
| 40082 | MRF8004 | |
| 40240 | MRF501 | |
| 40279 | 2N3375 | |
| 40280 | 2N4427 | |
| 40281 | 2N392 | |
| 40282 | 2N3927 | |
| 40290 | 2N3553 | |
| 40291 | 2N3632 | |
| 40340 | 2N5071 | |
| 40341 | 2N3950 | |
| 40446 | | MRF8004 |
| 40581 | | MRF8004 |
| 40582 | | MRF8004 |
| 40608 | 2N5943 | |
| 40637A | | 2N4072 |
| 40665 | | 2N3375 |
| 40666 | | 2N3632 |
| 40893 | | 2N5946 |
| 40894 | | 2N5179 |
| 40895 | | 2N5179 |
| 40896 | | 2N5179 |
| 40897 | | 2N5179 |
| 40915 | 2N5031 | |
| 40934 | MRF616 | |
| 40936 | 2N5070 | |
| 40940 | MRF5175 | |
| 40941 | | MRF313 |
| 40953 | MRF207 | |
| 40954 | MRF208 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| 40955 | MRF238 | |
| 40964 | MRF515 | |
| 40965 | MRF515 | |
| 40967 | 2N5944 | |
| 40968 | 2N5946 | |
| 40970 | MRF644 | |
| 40971 | MRF646 | |
| 40972 | MRF607 | |
| 40973 | 2N6081 | |
| 40974 | 2N6082 | |
| 40975 | 2N3553 | |
| 40976 | 2N3553 | |
| 40977 | 2N5642 | |
| 41008 | MRF628 | |
| 41008A | 2N5944 | |
| 41009 | MRF616 | |
| 41009A | 2N5944 | |
| 41010 | 2N5946 | |
| 41024 | 2N5108 | |
| 41025 | MRF321 | |
| 41026 | MRF323 | |
| 41027 | MRF321 | |
| 41028 | MRF323 | |
| 41038 | MRF905 | |
| 80091 | MRF511 | |
| 80099 | MRF525 | |
| 80167 | MRF511 | |
| 80231 | MRF511 | |
| A3-12 | MRF403 | |
| A3-28 | | 2N5641 |
| A25-12 | 2N5848 | |
| A25-28 | | MRF314 |
| AT004 | | MRF904 |
| AT0017 | MRF904 | |
| AT0017A | MRF904 | |
| AT0025 | MRF904 | |
| AT0025A | MRF904 | |
| AT25 | | MRF901 |
| AT25A | | MRF901 |
| AT25B | | MRF901 |
| AT50 | BFR90 | |
| AT51 | BFR90 | |
| AT52 | BFR90 | |
| AT1425 | | BFR90 |
| AT2625 | | MRF902 |
| AT2645 | MRF902 | |
| AT2645A | | MRF902 |
| AT2715 | MRF912 | |
| B1-12 | | 2N4427 |
| B2-8Z | | 2N6080 |
| B3-12 | 2N6080 | |
| B5-8Z | | 2N6081 |
| B8-12 | MRF212 | |
| B12-12 | 2N6081 | |
| B12-28 | | MRF314 |
| B15-12 | 2N6081 | |
| B25-12 | 2N6082 | |
| B25-28 | MRF314 | |
| B30-12 | 2N6083 | |
| B40-12 | 2N6084 | |
| B40-28 | MRF315 | |
| B45-12 | | 2N6084 |
| BAM20 | MRF314 | |
| BAM40 | MRF315 | |
| BAM80 | | MRF316 |
| BAM120 | | MRF317 |
| BFR49 | | MRF902 |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| BFR53 | | MMBR920 |
| BFR63 | MRF511 | |
| BFR64 | MRF511 | |
| BFR65 | MRF511 | |
| BFR90 | BFR90 | |
| BFR91 | BFR91 | |
| BFR92 | MMBR920 | |
| BFR93 | MMBR930 | |
| BFR94 | MRF511 | |
| BFR95 | | MRF517 |
| BFR96 | BFR96 | |
| BFS17 | | MMBR5179 |
| BFS22A | 2N3924 | |
| BFT24 | MRF911 | |
| BFT25 | MMBR931 | |
| BFW16A | MRF517 | |
| BFW17A | MRF517 | |
| BFW46 | 2N3924 | |
| BFW47 | 2N3553 | |
| BFW92 | BFW92 | |
| BFX89 | BFX89 | |
| BFY90 | BFY90 | |
| BGY22 | | MHW401 |
| BGY22A | | MHW401 |
| BGY23 | | MHW709 |
| BGY23A | | MHW709 |
| BGY36 | MHW602 | |
| BGY450 | | MHW595 |
| BLW60 | | MRF449A |
| BLW64 | MRF208 | |
| BLW75 | MRF226 | |
| BLX13 | MRF401 | |
| BLX14 | MRF464A | |
| BLX15 | MRF428A | |
| BLX65 | | MRF629 |
| BLX66 | MRF616 | |
| BLX67 | 2N5944 | |
| BLX68 | 2N5945 | |
| BLX69A | | 2N6136 |
| BLX91 | | MRF313A |
| BLX92 | MRF5174 | |
| BLX93 | MRF321 | |
| BLX94A | MRF5177A | |
| BLX95 | | MRF326 |
| BLX96 | | MRF321 |
| BLX97 | | MRF321 |
| BLX98 | | MRF323 |
| BLY53A | | 2N5946 |
| BLY57 | 2N3926 | |
| BLY58 | 2N3927 | |
| BLY59 | 2N3375 | |
| BLY60 | 2N3632 | |
| BLY87A | MRF212 | |
| BLY88A | 2N6081 | |
| BLY89A | 2N6082 | |
| BLY90 | | MRF243 |
| BLY91A | 2N5641 | |
| BLY92A | 2N5643 | |
| BLY93A | 2N5643 | |
| BM15-12 | MRF215 | |
| BM30-12 | MRF216 | |
| BM45-12 | MRF243 | |
| BM70-12 | MRF245 | |
| BM80-12 | MRF245 | |
| BM80-28 | MRF316 | |
| BM100-28 | MRF317 | |
| C1/2-12 | MRF626 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| C1-12 | MRF616 | |
| C1-12Z | 2N5944 | |
| C1-28 | | MRF313 |
| C2-8Z | | 2N5945 |
| C3-12 | 2N5645 | |
| C3-28 | MRF5175 | |
| C5-8Z | | 2N5946 |
| C5-12 | 2N5945 | |
| C10-12A | 2N5946 | |
| C12-12 | 2N5646 | |
| C12-28 | MRF321 | |
| C25-12 | 2N6136 | |
| C25-28 | MRF323 | |
| C40-28 | | MRF326 |
| C50-28 | | 2N6439 |
| C2M50-28R | | 2N6439 |
| C2M60-28R | 2N6439 | |
| C2M70-28R | MRF327 | |
| C2M100-28 | | MRF327 |
| CA100 | | MHW1171 |
| CA200 | | MHW1172 |
| CA416 | | MHW1182 |
| CA418 | MHW1182 | |
| CA601B/U | | MHW1342 |
| CA636 | MHW1642 | |
| CA801 | MHW590 | |
| CA804 | MHW590 | |
| CA860 | MHW590 | |
| CA870 | MHW590 | |
| CA2100 | MHW1171 | |
| CA2200 | MHW1172 | |
| CA2600 | MHW1342 | |
| CD1752 | | MRF317 |
| CD1802 | MRF226 | |
| CD1803 | MRF209 | |
| CD1979 | | MRF321 |
| CD2035 | | MRF5175 |
| CD2087 | | MRF5175 |
| CD2088 | MRF321 | |
| CD2089 | MRF323 | |
| CD2514 | | 2N6081 |
| CD2545 | | MRF450 |
| CD2810 | | MRF321 |
| CD3400 | | MRF315 |
| CD3401 | | MRF316 |
| CD3403 | | MRF317 |
| CD3550 | | MRF315 |
| CD5918 | MRF321 | |
| CD5919A | MRF323 | |
| CD5944 | 2N5944 | |
| CD5945 | 2N5945 | |
| CD5946 | 2N5946 | |
| CD6105 | | MRF5177A |
| CD6105A | | MRF5177A |
| CD7012 | MRF454 | |
| CM10-12A | MRF641 | |
| CM20-12A | MRF644 | |
| CM25-28 | MRF325 | |
| CM30-12A | MRF646 | |
| CM45-12A | MRF646 | |
| CM45-28 | MRF326 | |
| CM50-12A | MRF648 | |
| CM60-12A | MRF648 | |
| CM80-28 | MRF327 | |
| CM80-28R | MRF327 | |
| CTC14 | MRF464A | |
| CTC15 | MRF428A | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| D1/2-12 | | MRF816 |
| D1-12B | | MRF817 |
| D1-12E | | MRF817 |
| D2-12B | | MRF817 |
| DM3-7BA | | MRF840 |
| DM5-12BA | | MRF840 |
| DM10-12BA | MRF840 | |
| DM15-12BA | MRF842 | |
| DM20-12BA | MRF842 | |
| DM30-12BA | MRF844 | |
| DM40-12BA | MRF846 | |
| DM45-12BA | | MRF846 |
| JO1006 | MRF315 | |
| JO1008 | | MRF317 |
| JO2000 | MRF5177A | |
| JO2005 | MRF5177A | |
| JO2007A | 2N6439 | |
| JO2009 | MRF325 | |
| JO2015 | MRF327 | |
| JO2016 | | MRF327 |
| JO2401 | | MRF326 |
| JO3025 | MRF644 | |
| JO3030 | MRF646 | |
| JO3040 | MRF646 | |
| JO3055 | MRF648 | |
| JO4020 | MRF215 | |
| JO4030 | MRF216 | |
| JO4040 | MRF216 | |
| JO4070 | MRF245 | |
| LT1001 | MRF517 | |
| LT2001 | MRF511 | |
| MHW401 | MHW401 | |
| MHW580 | MHW580 | |
| MHW590 | MHW590 | |
| MHW591 | MHW591 | |
| MHW592 | MHW592 | |
| MHW593 | MHW593 | |
| MHW594 | MHW594 | |
| MHW595 | MHW595 | |
| MHW601 | MHW601 | |
| MHW602 | MHW602 | |
| MHW603 | MHW603 | |
| MHW709 | MHW709 | |
| MHW710 | MHW710 | |
| MHW1171 | MHW1171 | |
| MHW1172 | MHW1172 | |
| MHW1182 | MHW1182 | |
| MHW1221 | MHW1221 | |
| MHW1222 | MHW1222 | |
| MHW1341 | MHW1341 | |
| MHW1342 | MHW1342 | |
| MM439 | | 2N4959 |
| MM1500 | | MRF905 |
| MM1500A | | MRF905 |
| MM1501 | | MRF905 |
| MM1501A | | MRF905 |
| MM1510 | | 2N5851 |
| MM1511 | | 2N5852 |
| MM1549 | | 2N5635 |
| MM1550 | | 2N5636 |
| MM1551 | | 2N5637 |
| MM1557 | | 2N5641 |
| MM1558 | | 2N5642 |
| MM1559 | | 2N5643 |
| MM1561 | | 2N6166 |
| MM1601 | | 2N5589 |
| MM1602 | | 2N5590 |

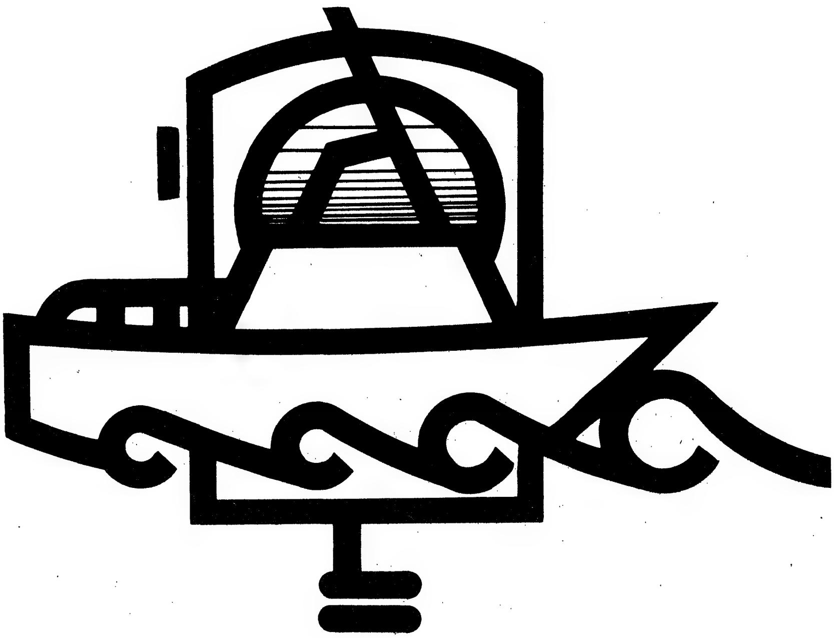
| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| MM1603 | | 2N5591 |
| MM1605 | | 2N5841 |
| MM1606 | | 2N5842 |
| MM1607 | | 2N5842 |
| MM1608 | | 2N5846 |
| MM1612 | | 2N6255 |
| MM1618 | | 2N5847 |
| MM1620 | | 2N5849 |
| MM1622 | | 2N5849 |
| MM1632 | | 2N5941 |
| MM1633 | | 2N5942 |
| MM1646 | | 2N5849 |
| MM1660 | | 2N5644 |
| MM1661 | | 2N5645 |
| MM1662 | | 2N5646 |
| MM1665 | | 2N6136 |
| MM1666 | | 2N6082 |
| MM1667 | | 2N6083 |
| MM1668 | | 2N6084 |
| MM1669 | | 2N6084 |
| MM1680 | | 2N6080 |
| MM1681 | | 2N6081 |
| MM1713 | | 2N4072 |
| MM1943 | | 2N4072 |
| MM1945 | | 2N4072 |
| MM4020 | | 2N6094 |
| MM4021 | | 2N6095 |
| MM4022 | | 2N6096 |
| MM4023 | | 2N6097 |
| MM4500 | | 2N5583 |
| MM5177 | | MRF5177 |
| MM8002 | 2N5943 | |
| MM8003 | MRF511 | |
| MM8004 | | MRF8004 |
| MM8006 | | 2N5031 |
| MM8007 | | 2N5032 |
| MM8008 | | MRF905 |
| MM8010 | | MRF905 |
| MM8011 | | MRF905 |
| MM8012 | | 2N5947 |
| MM8020 | | 2N5836 |
| MM8021 | | 2N5837 |
| MM8023 | | 2N5943 |
| MRF201 | | 2N6255 |
| MRF203 | | MRF245 |
| MRF207 | MRF207 | |
| MRF208 | MRF208 | |
| MRF209 | MRF209 | |
| MRF212 | MRF212 | |
| MRF215 | MRF215 | |
| MRF216 | MRF216 | |
| MRF221 | MRF221 | |
| MRF222 | MRF222 | |
| MRF223 | MRF223 | |
| MRF224 | MRF224 | |
| MRF225 | MRF225 | |
| MRF226 | MRF226 | |
| MRF227 | MRF227 | |
| MRF230 | MRF230 | |
| MRF231 | MRF231 | |
| MRF232 | MRF232 | |
| MRF233 | MRF233 | |
| MRF234 | MRF234 | |
| MRF237 | MRF237 | |
| MRF238 | MRF238 | |
| MRF243 | MRF243 | |
| MRF244 | MRF245 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| MRF245 | MRF245 | |
| MRF305 | MRF325 | |
| MRF306 | 2N6439 | |
| MRF313,A | MRF313,A | |
| MRF314 | MRF314 | |
| MRF315 | MRF315 | |
| MRF316 | MRF316 | |
| MRF317 | MRF317 | |
| MRF321 | MRF321 | |
| MRF323 | MRF323 | |
| MRF325 | MRF325 | |
| MRF326 | MRF326 | |
| MRF327 | MRF327 | |
| MRF401 | MRF401 | |
| MRF402 | MRF402 | |
| MRF404 | MRF404 | |
| MRF406 | MRF406 | |
| MRF415 | | 2N6366 |
| MRF416 | | 2N6367 |
| MRF417 | | 2N6368 |
| MRF418 | MRF418 | |
| MRF418 | MRF460 | |
| MRF419 | | 2N6370 |
| MRF420 | MRF454 | |
| MRF421 | MRF421 | |
| MRF422,A | MRF422,A | |
| MRF427,A | MRF427,A | |
| MRF428,A | MRF428,A | |
| MRF432 | MRF432 | |
| MRF433 | MRF433 | |
| MRF449,A | MRF449,A | |
| MRF450,A | MRF450,A | |
| MRF451 | MRF453 | |
| MRF452 | MRF453 | |
| MRF453,A | MRF453,A | |
| MRF454,A | MRF454,A | |
| MRF455,A | MRF455,A | |
| MRF460 | MRF460 | |
| MRF463 | MRF463 | |
| MRF464,A | MRF464,A | |
| MRF475 | MRF475 | |
| MRF501 | MRF501 | |
| MRF502 | MRF502 | |
| MRF504 | | 2N6135 |
| MRF509 | MRF509 | |
| MRF511 | MRF511 | |
| MRF515 | MRF515 | |
| MRF517 | MRF517 | |
| MRF519 | | MRF517 |
| MRF525 | MRF525 | |
| MRF531 | MRF531 | |
| MRF601 | | 2N6256 |
| MRF602 | | 2N6136 |
| MRF603 | MRF603 | |
| MRF604 | MRF604 | |
| MRF605 | | MRF306 |
| MRF606 | MRF606 | |
| MRF607 | MRF607 | |
| MRF618 | MRF641 | |
| MRF619 | MRF644 | |
| MRF620 | MRF644 | |
| MRF621 | MRF646 | |
| MRF626 | MRF626 | |
| MRF627 | MRF627 | |
| MRF628 | MRF628 | |
| MRF629 | MRF629 | |
| MRF816 | MRF816 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| MRF817 | MRF817 | |
| MRF818 | MRF818 | |
| MRF901 | MRF901 | |
| MRF902 | MRF902 | |
| MRF904 | MRF904 | |
| MRF905 | MRF905 | |
| MRF911 | MRF911 | |
| MRF912 | MRF912 | |
| MRF914 | MRF914 | |
| MRF931 | MRF931 | |
| MRF5174 | MRF5174 | |
| MRF5175 | MRF5175 | |
| MRF5176 | MRF5176 | |
| MRF5177,A | MRF5177,A | |
| MRF5178 | | 2N6439 |
| MRF8003 | MRF8003 | |
| MRF8004 | MRF8004 | |
| MX1.5 | | MHW401 |
| MX7.5 | MHW709 | |
| MX12 | MHW710 | |
| MX15 | MHW710 | |
| MV20 | MHW602 | |
| MV30 | MHW603 | |
| PH0401H | | MRF5174 |
| PH0403H | MRF5175 | |
| PH0406H | | MRF5175 |
| PH0412H | MRF321 | |
| PH0425H | MRF325 | |
| PH0450D | 2N6439 | |
| PH0450H | 2N6439 | |
| PH0501H | | MRF5175 |
| PH0503H | | MRF5175 |
| PH0506H | MRF321 | |
| PH0512H | MRF321 | |
| PH0525H | MRF325 | |
| PH0550H | 2N6439 | |
| PH8193 | | MRF905 |
| PT3501 | MRF230 | |
| PT3503 | | MRF232 |
| PT3537 | | 2N5944 |
| PT3570 | 2N5947 | |
| PT3571 | 2N5943 | |
| PT3571A | 2N5943 | |
| PT4537 | | 2N6080 |
| PT4544 | | MRF212 |
| PT4555 | | MRF234 |
| PT4556 | | MRF450A |
| PT4570 | 2N5947 | |
| PT4572A | 2N5947 | |
| PT4574 | MRF511 | |
| PT4578 | MRF517 | |
| PT4579 | 2N5943 | |
| PT5695 | | MRF233 |
| PT5701 | MRF402 | |
| PT8549 | | 2N6081 |
| PT8551 | 2N3553 | |
| PT8717 | MRF231 | |
| PT8740 | | MRF629 |
| PT8769 | MRF233 | |
| PT8809 | 2N5944 | |
| PT8810 | 2N5945 | |
| PT8811 | 2N5946 | |
| PT8825 | | 2N6136 |
| PT8828 | MRF212 | |
| PT8837 | 2N6081 | |
| PT8838 | 2N6084 | |
| PT9700 | MRF5174 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|
| PT9701 | MRF5175 | |
| PT9702 | MRF323 | |
| PT9703 | MRF321 | |
| PT9704 | | MRF5177A |
| PT9704A | | MRF5177A |
| PT9730 | | 2N5641 |
| PT9731 | MRF314 | |
| PT9732 | 2N5641 | |
| PT9733 | MRF315 | |
| PT9734 | MRF314 | |
| PT9776 | MRF455 | |
| PT9776A | MRF455A | |
| PT9780 | | MRF464 |
| PT9780A | | MRF464A |
| PT9782 | | MRF317 |
| PT9782A | | MRF317 |
| PT9783 | | 2N5941 |
| PT9783A | | MRF400 |
| PT9784 | MRF455 | |
| PT9784A | MRF455A | |
| PT9785 | MRF421 | |
| PT9787 | 2N6370 | |
| PT9787A | | 2N6370 |
| PT9788 | | 2N5941 |
| PT9788A | MRF401 | |
| PT9790 | MRF428 | |
| PT9790A | MRF428A | |
| PT9795 | MRF433 | |
| PT9795A | | 2N6081 |
| PT9796 | MRF449 | |
| PT9796A | MRF449A | |
| PT9797 | MRF450 | |
| PT9797A | MRF450A | |
| R47M10 | MHW709 | |
| R47M13 | MHW710 | |
| R47M15 | MHW710 | |
| RF1003 | MRF221 | |
| RF1004 | MRF223 | |
| RF2081 | MRF216 | |
| RF2092 | | MRF460 |
| RF2123 | MRF238 | |
| RF2125 | | MRF450 |
| RF2127 | MRF245 | |
| RF2135 | MRF223 | |
| RF2142 | 2N6367 | |
| RF2143 | | MRF454 |
| RF2144 | MRF224 | |
| RF2146 | MRF476 | |
| RF2147 | MRF475 | |
| S10-12 | MRF433 | |
| S10-28 | 2N6370 | |
| S15-50 | MRF427 | |
| S50-12 | MRF450 | |
| S50-28 | MRF464 | |
| S80-12 | MRF454 | |
| S100-12 | MRF421 | |
| S100-28 | MRF422 | |
| S100-50 | MRF428 | |
| S175-28 | | MRF422 |
| S175-50 | | MRF428 |
| SD1005 | MRF511 | |
| SD1006 | 2N5943 | |
| SD1012 | 2N5590 | |
| SD1014 | MRF233 | |
| SD1015 | MRF315 | |
| SD1019 | | MRF317 |
| SD1019-5 | 2N6166 | |
| SD1020 | MRF402 | |
| SD1020-6 | MRF313A | |
| SD1020-7 | MRF313 | |
| SD1068 | | MRF230 |
| SD1069 | | 2N5847 |
| SD1074 | MRF453 | |
| SD1076 | MRF454 | |
| SD1077 | MRF8004 | |
| SD1080 | MRF207 | |
| SD1080-2 | MRF628 | |
| SD1080-4 | MRF604 | |
| SD1080-6 | MRF627 | |
| SD1080-7 | MRF626 | |
| SD1087 | MRF641 | |
| SD1088 | MRF644 | |
| SD1089 | MRF646 | |
| SD1095 | | MRF840 |
| SD1096 | | MRF842 |
| SD1098 | | MRF844 |
| SD1099 | | MRF846 |
| SD1115-4 | MRF607 | |
| SD1124 | MRF245 | |
| SD1127 | MRF237 | |
| SD1131 | MRF629 | |
| SD1133 | MRF212 | |
| SD1133-1 | | MRF212 |
| SD1134 | 2N5944 | |
| SD1134-1 | MRF225 | |
| SD1135 | 2N5945 | |
| SD1136 | 2N5946 | |
| SD1143 | MRF212 | |
| SD1147 | MRF5175 | |
| SD1148 | MRF321 | |
| SD1149 | MRF323 | |
| SD1166 | MRF403 | |
| SD1167 | 2N5847 | |
| SD1168 | 2N5848 | |
| SD1169 | 2N5849 | |
| SD1174 | 2N6255 | |
| SD1177 | | 2N5589 |
| SD1200 | 2N3866 | |
| SD1216 | 2N5591 | |
| SD1218 | MRF209 | |
| SD1219 | | MRF316 |
| SD1229 | 2N6083 | |
| SD1229-1 | MRF222 | |
| SD1232 | MRF517 | |
| SD1242-5 | | 2N5641 |
| SD1244-6 | | 2N5642 |
| SD1256 | | 2N5589 |
| SD1262 | MRF226 | |
| SD1288 | MRF453A | |
| SD1289 | MRF453 | |
| SD1290 | 2N5849 | |
| SD1295 | MRF421 | |
| SD1299 | MRF326 | |
| SD1300 | BFY90 | |
| SD1303 | 2N3839 | |
| SD1308 | MRF905 | |
| SD1347-7 | MRF402 | |
| V912 | MRF902 | |

| PART NO. | MOTOROLA DIRECT REPLACEMENT | MOTOROLA SIMILAR REPLACEMENT |
|---|---|---|



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6367

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

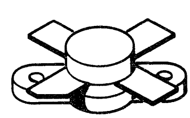
. . . designed primarily for driver applications in 12.5 volt single-sideband amplifiers from 2.0 to 30 MHz.

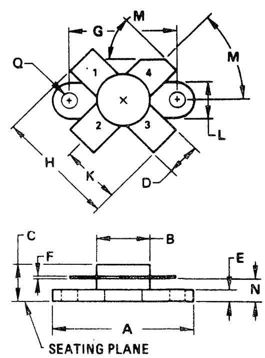
- Specified 12.5 Volt, 50 MHz Characteristics —
  Output Power = 9.0 W (PEP)
  Minimum Gain = 14 dB
  Efficiency = 36%
- Intermodulation Distortion @ 9.0 W (PEP) —
  IMD = -36 dB (Max)

**9 W (PEP) — 30 MHz**

**RF POWER TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 2.0 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 20<br>0.114 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

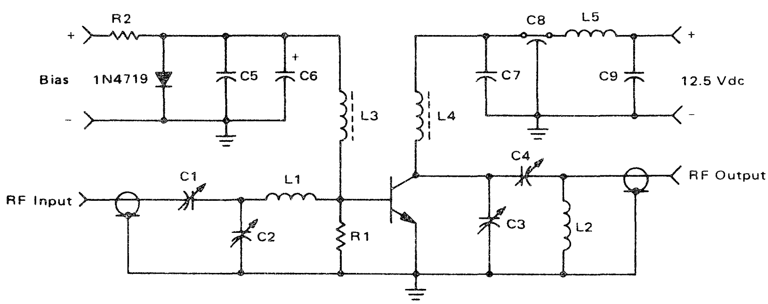
*Indicates JEDEC Registered Data.

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | $I_{CES}$ | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | 50 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 500 mAdc, $V_{CE}$ = 12.5 Vdc, f = 50 MHz) | $f_T$ | 50 | – | MHz |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 90 | pF |
| **FUNCTIONAL TESTS** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 9.0 W(PEP), $I_{C(max)}$ = 1.0 Adc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 14 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 9.0 W(PEP), $I_{C(max)}$ = 1.0 Adc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 36 | – | % |
| Intermodulation Distortion (1) ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 9.0 W(PEP), $I_{C(max)}$ = 1.0 Adc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -36 | dB |

*Indicates JEDEC Registered Data
(1) To proposed E.I.A. Specifications

FIGURE 1 – 30 MHz TEST CIRCUIT




| | | | |
|---|---|---|---|
| C1,C3 | 25-280 pF, ARCO 464 or Equivalent | L2 | 5 Turns, #18 AWG, 1/4" ID, 5/16" Long (0.13 μH) |
| C2,C4 | 170-780 pF, ARCO 469 or Equivalent | L3 | 3.3 μH |
| C5,C7,C9 | 0.1 μF | L4 | 1.0 μH |
| C6 | 500 μF TANTALUM | L5 | FERROXCUBE VK200 20/4B |
| C8 | 680 pF Feedthru | R1 | 10 Ohms |
| L1 | 3 Turns, #18 AWG, 1/4" ID, 1/4" Long (60 nH) | R2 | 50 Ohms |

Adjust Bias for $I_{CQ}$ = 35 mA with no RF Signal applied

FIGURE 2 – LINEAR OUTPUT POWER versus FREQUENCY

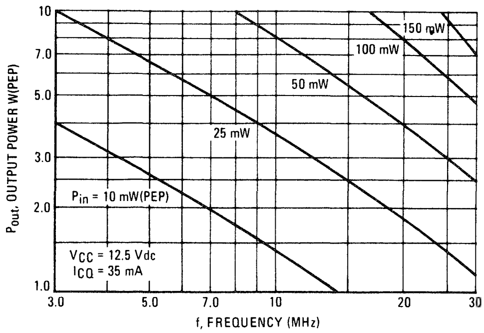



FIGURE 3 – OUTPUT POWER versus INPUT POWER

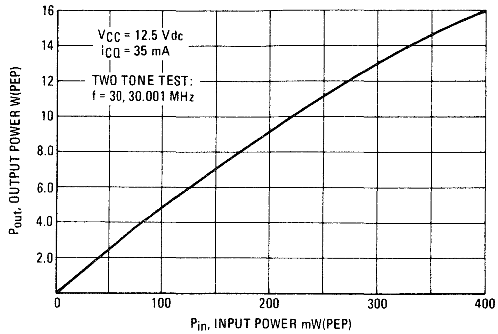



FIGURE 4 – OUTPUT POWER versus INPUT POWER

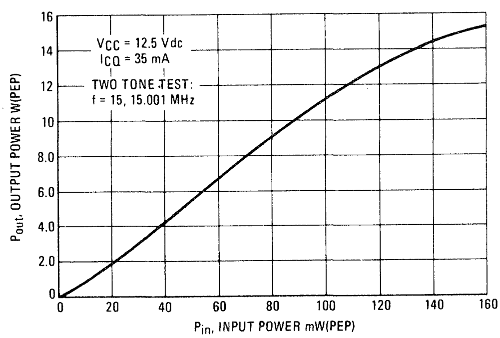



FIGURE 5 – OUTPUT POWER versus INPUT POWER

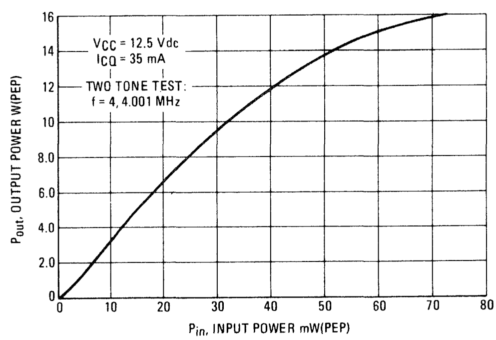



FIGURE 6 – INTERMODULATION DISTORTION versus OUTPUT POWER

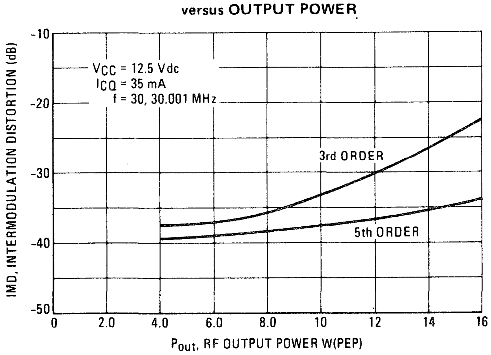



FIGURE 7 – LINEAR OUTPUT POWER versus SUPPLY VOLTAGE

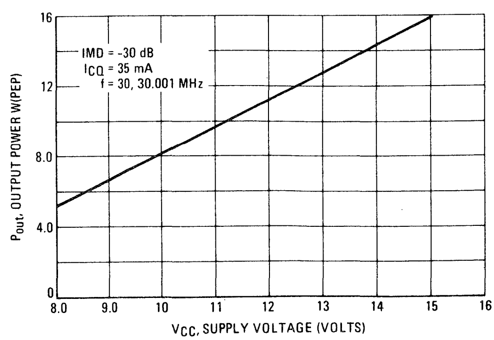


FIGURE 8 – PARALLEL EQUIVALENT INPUT RESISTANCE

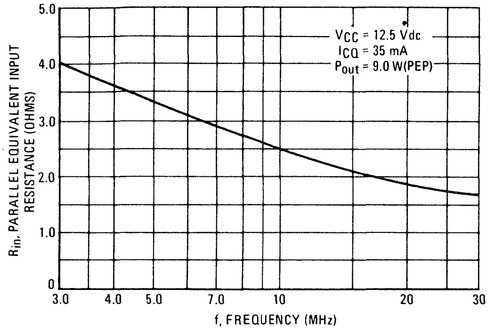



FIGURE 9 – PARALLEL EQUIVALENT INPUT CAPACITANCE

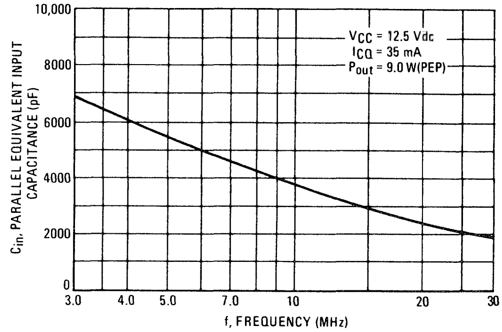



FIGURE 10 – PARALLEL EQUIVALENT OUTPUT RESISTANCE

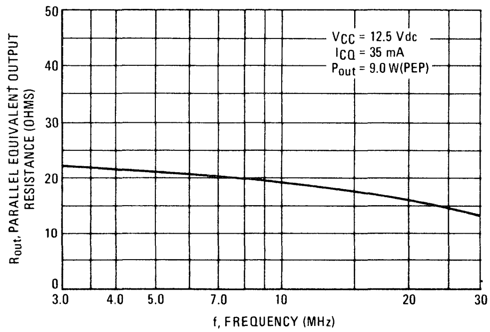



FIGURE 11 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE

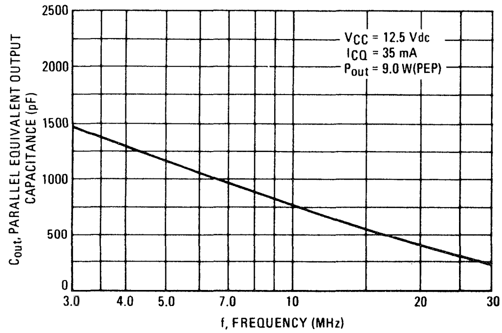



FIGURE 12 – CURRENT-GAIN – BANDWIDTH PRODUCT

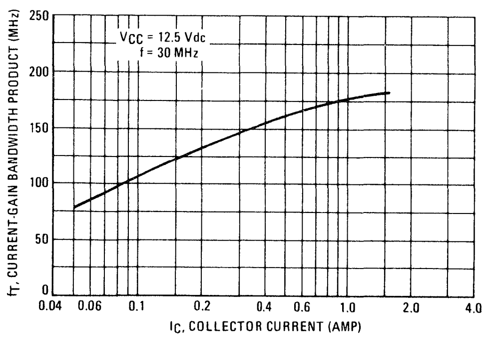



FIGURE 13 – COLLECTOR CURRENT versus BASE-EMITTER VOLTAGE

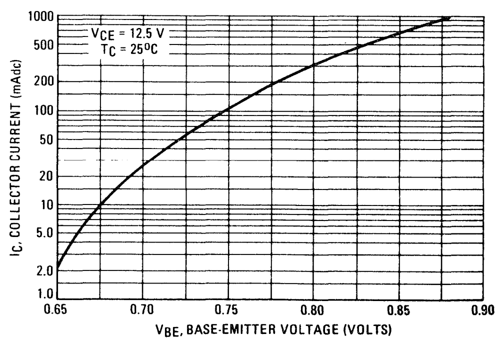


FIGURE 14 — OUTPUT CAPACITANCE

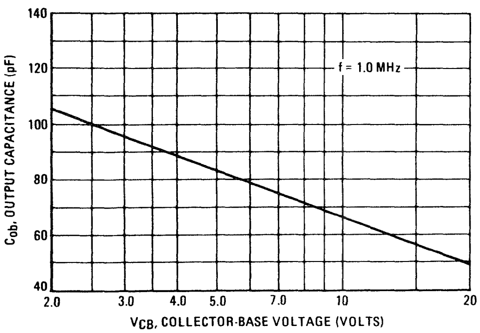



FIGURE 15 — INPUT CAPACITANCE

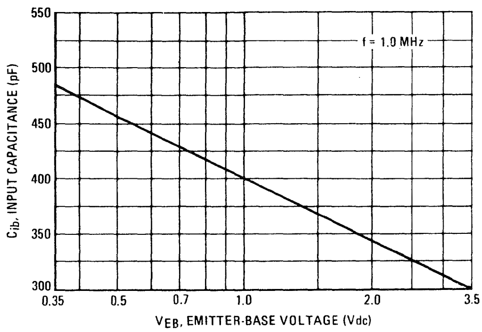



FIGURE 16 — DC SAFE OPERATING AREA

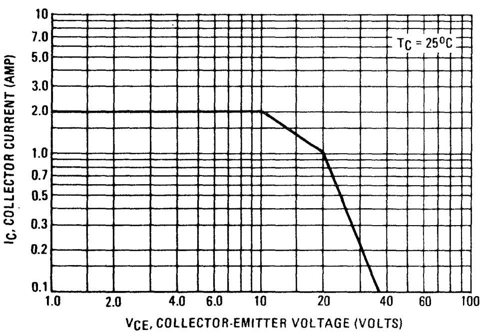
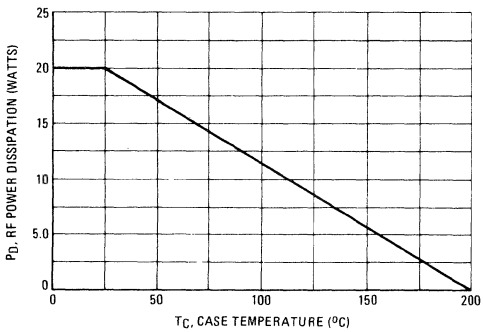



FIGURE 17 — RF POWER DISSIPATION



2

# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

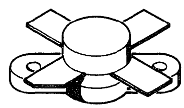
# MRF406

## The RF Line

**20 W(PEP) – 30 MHz**

**RF POWER TRANSISTOR**

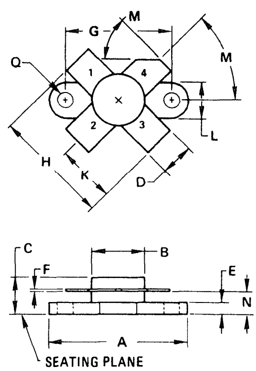
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for application as a power linear amplifier from 2.0 to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 20 W(PEP)
  Minimum Gain = 12 dB
  Efficiency = 45%
- Intermodulation Distortion @ 20 W(PEP) –
  IMD = -30 dB (Min)
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 4.0 | Adc |
| Withstand Current (t = 5.0 s) | – | 12 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above 25°C | $P_D$ | 80<br>0.46 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

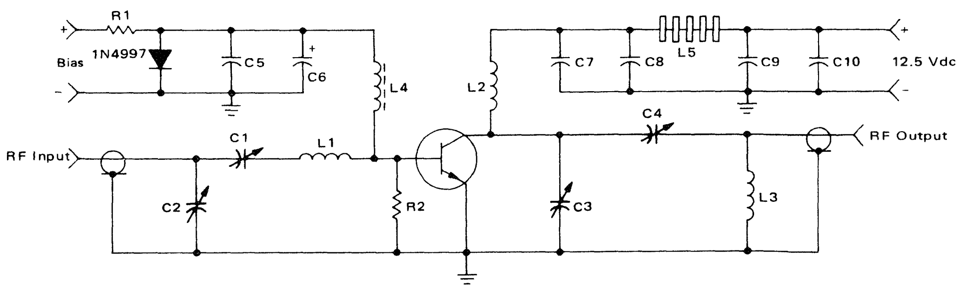
### THERMAL CHARACTERISTICS

| Characteristics | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.2 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 40 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 50 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 12.5 Vdc, $V_{BE}$ = 0) | $I_{CES}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 35 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 150 | 200 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 20 W(PEP), $I_{C(max)}$ = 1.75 Adc, $I_{CQ}$ = 25 mAdc, f = 30, 30.001 MHz) | $G_{PE}$ | 12 | 15 | – | dB |
| Power Output ($V_{CE}$ = 12.5 Vdc, f = 30 MHz) | $P_{out}$ | 20 | – | – | Watts (PEP) |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 20 W(PEP), $I_{C(max)}$ = 1.75 Adc, $I_{CQ}$ = 25 mAdc, f = 30, 30.001 MHz) | $\eta$ | 45 | – | – | % |
| Intermodulation Distortion ($V_{CE}$ = 12.5 Vdc, $P_{out}$ = 20 W(PEP), $I_{C(max)}$ = 1.75 Adc, $I_{CQ}$ = 25 Adc, f = 30, 30.001 MHz) | IMD | −30 | −35 | – | dB |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 20 W(PEP), $I_C$ = 1.75 Adc, $I_{CQ}$ = 25 mAdc, f = 30, 30.001 MHz) | – | > 30:1 All Phase Angles | | | – |

**FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC**




| | |
|---|---|
| C1, C2, C4 | ARCO 466 |
| C3 | ARCO 469 |
| C5, C8, C9 | 0.1 μF Disc Ceramic |
| C6 | 1000 μF, 3 V Electrolytic |
| C7 | 1000 pF, UNELCO |
| C10 | 100 μF, 15 V Electrolytic |
| R1 | 100 Ohm, 25 W, Wire Wound |
| R2 | 10 Ohm, ½ W, Carbon |
| L1 | 0.15 μH, Molded Choke |
| L2 | 15 Turns of #20 AWG Enameled Wire, 1/4" I.D., Close Wound |
| L3 | 4 Turns of #18 AWG Wire, 5/16" I.D., 3/8" Long. |
| L4 | 10 μH, Molded Choke |
| L5 | 5 Ferrite Beads, FERROXCUBE #56-590-65/3B |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

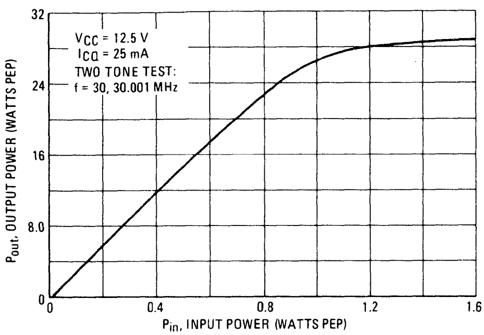



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

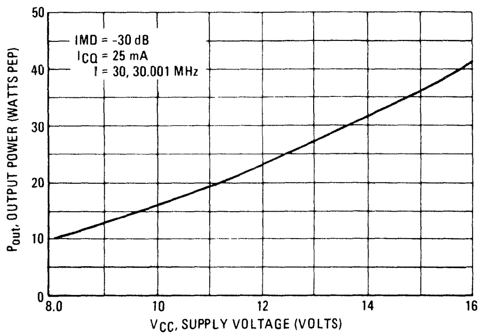



FIGURE 4 – POWER GAIN versus FREQUENCY

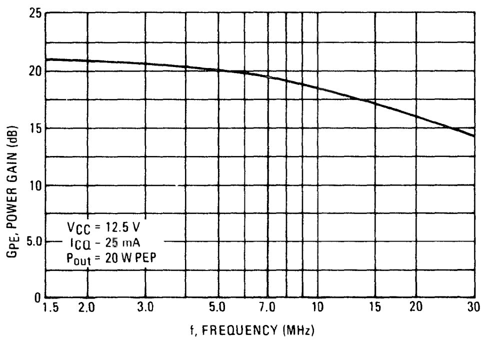



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER

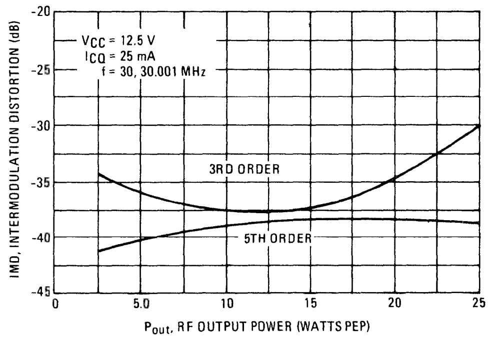



FIGURE 6 – DC SAFE OPERATING AREA

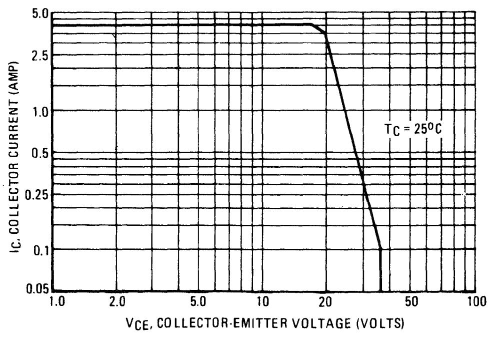
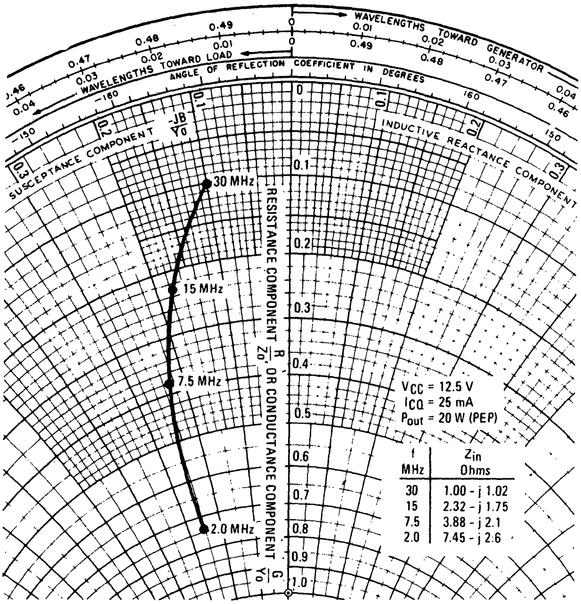


FIGURE 7 – SERIES EQUIVALENT IMPEDANCE




| f MHz | $Z_{in}$ Ohms |
|---|---|
| 30 | 1.00 - j 1.02 |
| 15 | 2.32 - j 1.75 |
| 7.5 | 3.88 - j 2.1 |
| 2.0 | 7.45 - j 2.6 |

FIGURE 8 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

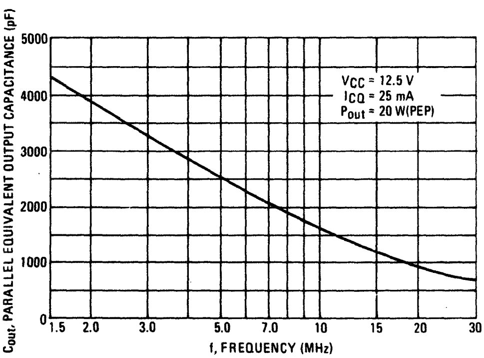
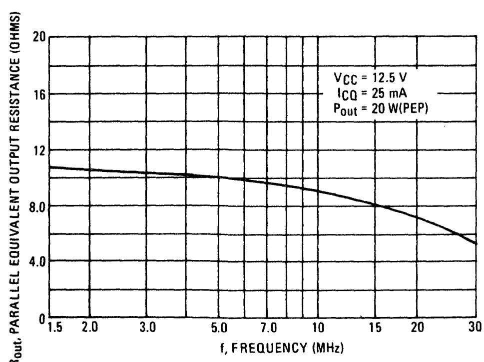



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036


# MRF421

## The RF Line

100 W(PEP) – 30 MHz

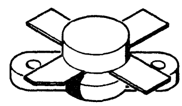
RF POWER
TRANSISTOR

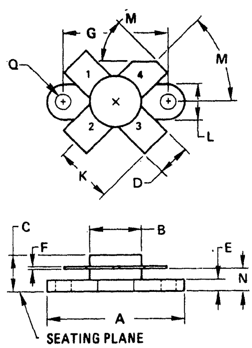
NPN SILICON

### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for application as a high-power linear amplifier from 2.0 to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 100 W(PEP)
  Minimum Gain = 10 dB
  Efficiency = 40%
- Intermodulation Distortion @ 100 W (PEP) –
  IMD = -30 dB (Min)
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.31 | 6.63 | 0.209 | 0.261 |
| D | 6.10 | 6.60 | 0.240 | 0.260 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 12.32 | – | 0.485 | – |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.30 | 4.06 | 0.130 | 0.160 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-08

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 45 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 20 | Adc |
| Withstand Current – 10 s | – | 30 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 200<br>1.14 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

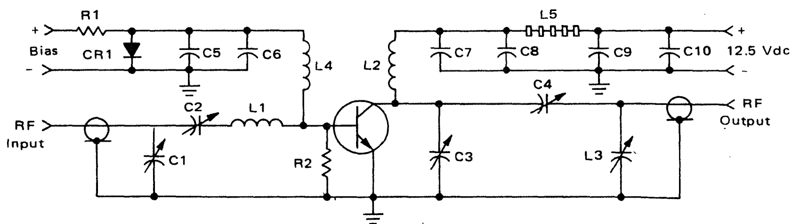
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.875 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 45 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 200 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 45 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 16 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 30 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | 550 | 650 | – | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 100 W, $I_{C(max)}$ = 10 Adc, $I_{CQ}$ = 150 mAdc, f = 30, 30.001 MHz) | $G_{PE}$ | 10 | 12 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 100 W, $I_{C(max)}$ = 10 Adc, $I_{CQ}$ = 150 mA, f = 30, 30.001 MHz) | $\eta$ | 40 | – | – | % |
| Intermodulation Distortion (1) ($V_{CE}$ = 12.5 Vdc, $P_{out}$ = 100 Watts, $I_C$ = 10 Adc, $I_{CQ}$ = 150 mA, f = 30, 30.001 MHz) | IMD | – | -33 | -30 | dB |

(1) To proposed EIA measurement technique.

FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC




C1,C2,C4 – 170-780 pF, ARCO 469
C3 – 80-480 pF, ARCO 466
C5,C7,C10 – ERIE 0.1 μF, 100 V
C6 – MALLORY 500 μF @ 15 V Electrolytic
C9 – 100 μF, 15 V Electrolytic
C8 – 1000 pF, 350 V UNDERWOOD
R1 – 10 Ω, 25 Watt Wirewound
R2 – 10 Ω, 1 Watt Carbon
CR1 – IN4997
L1 – 3 Turns, #16 Wire, 5/16" I.D., 5/16" Long
L2 – 12 Turns, #16 Enamaled Wire Closewound, 1/4" I.D.
L3 – 1 3/4 Turns, 1/8" Tubing, 3/8" I.D., 3/8" Long
L4 – 10 μH Molded Choke
L5 – 10 Ferrite Beads - FERROXCUBE #56-590-65/3B

FIGURE 2 – OUTPUT POWER versus INPUT POWER

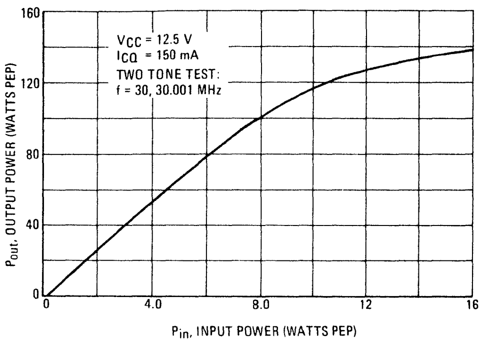



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

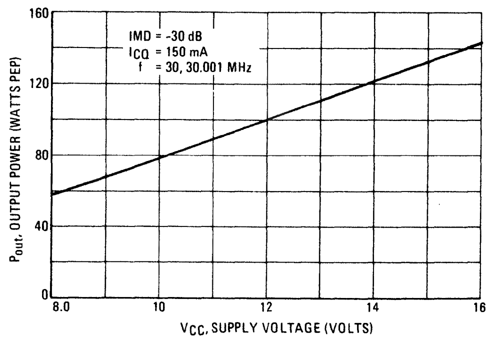



FIGURE 4 – POWER GAIN versus FREQUENCY

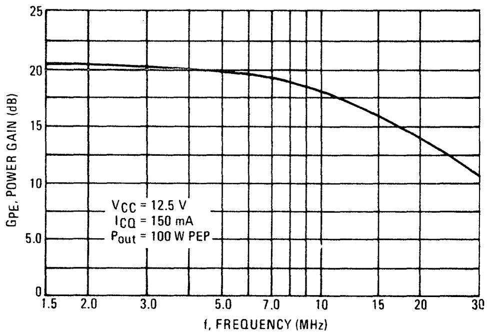



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER

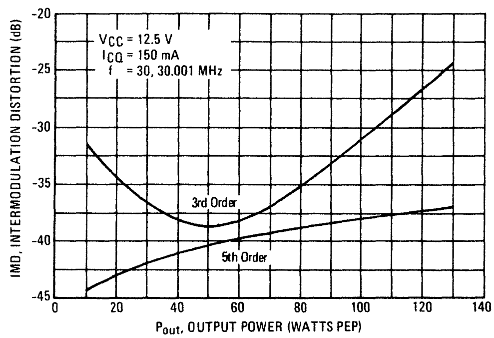



FIGURE 6 – DC SAFE OPERATING AREA

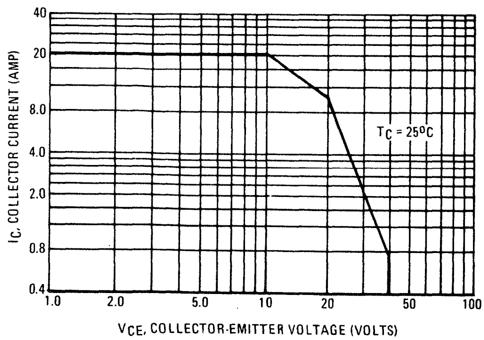
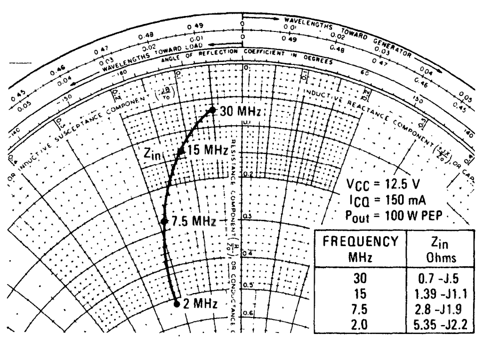



FIGURE 7 – SERIES EQUIVALENT IMPEDANCE




| FREQUENCY MHz | $Z_{in}$ Ohms |
|---|---|
| 30 | 0.7 -J.5 |
| 15 | 1.39 -J1.1 |
| 7.5 | 2.8 -J1.9 |
| 2.0 | 5.35 -J2.2 |

FIGURE 8 — OUTPUT CAPACITANCE versus FREQUENCY

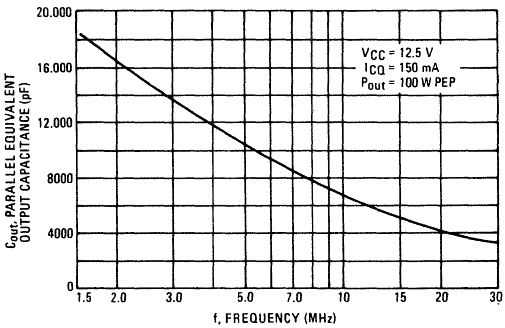
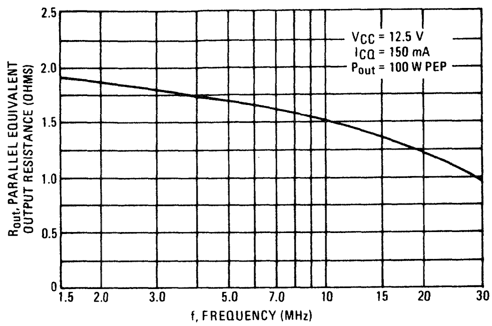



FIGURE 9 — OUTPUT RESISTANCE versus FREQUENCY



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF432
# MRF433
# MK433*

## The RF Line

### SILICON RF POWER TRANSISTORS

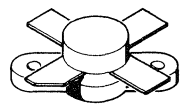
. . . designed primarily for application as complementary symmetry amplifiers in linear amplifiers from 2.0 to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characterisitcs –
  Output Power = 12.5 W (PEP)
  Minimum Gain = 20 dB
  Efficiency = 50%
- Intermodulation Distortion @ 12.5 W (PEP) –
  IMD = -30 dB (Max)
- Available as Matched Pairs for Complementary Symmetry Amplifier Applications

*For Matched Pairs Order MK433

**12.5 W (PEP) – 30 MHz**
**RF POWER TRANSISTORS**

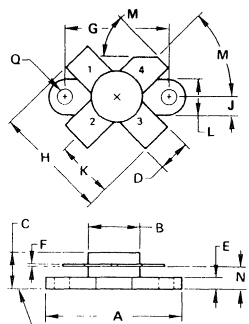
**MRF432 – PNP SILICON**
**MRF433 – NPN SILICON**



**MATCHING PROCEDURE**

In the push-pull circuit configuration two device parameters are critical for optimum circuit performance. These parameters are $V_{BE(on)}$ and $h_{FE}$. Both parameters can be guaranteed by measuring $I_{CQ}$ of the devices and selecting pairs with a $\Delta I_{CQ} \leq 10$ mAdc.

Actual $I_{CQ}$ matching is performed in the test circuit with a $V_{CE}$ equal to 12.5 Volts. The base bias supply is adjusted to set $I_{CQ}$ equal to 40 mAdc using a reference standard transistor. The $I_{CQ}$ of all production MRF432/MRF433 transistors is measured using this base bias supply setting. The production transistors are tested and categorized in ranges of 10 mAdc. Finally, the devices are stocked as pairs with a guaranteed $\Delta I_{CQ} \leq 10$ mAdc.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

**CASE 211-07**

MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 20<br>114 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

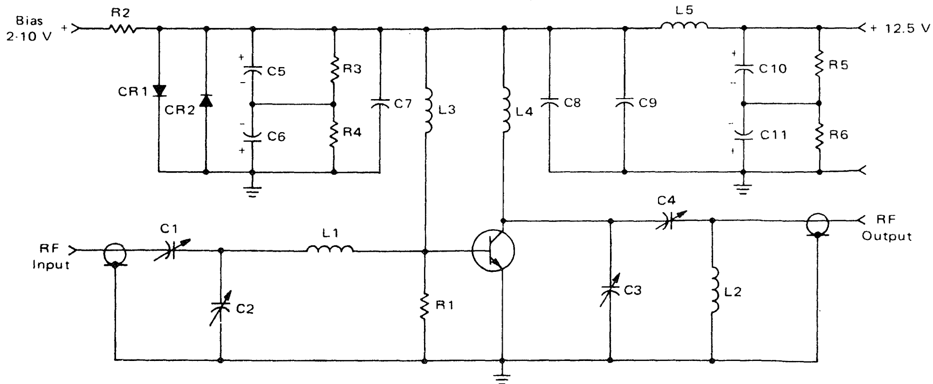
**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | $I_{CES}$ | – | – | 8.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 0.5 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 15 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 70 | 120 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain(1) ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12.5 W (PEP), $I_{CQ}$ = 100 mAdc, f = 30,30.001 MHz) | $G_{pe}$ | 20 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12.5 W (PEP) (f = 30,30.001 MHz) | $\eta$(1)<br>$\eta$(2) | 45<br>40 | 50<br>45 | – | % |
| Intermodulation Distortion ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12.5 W (PEP), $I_{CQ}$ = 100 mAdc, f = 30, 30.001 MHz) | IMD | – | – | -30 | dB |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12.5 W (PEP), $I_{CQ}$ = 100 mAdc, f = 30,30.001 MHz) | $Z_{in}$ | – | 2.50-j2.20 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12.5 W (PEP), $I_{CQ}$ = 100 mAdc, f = 30, 30.001 MHz) | $Z_{out}$ | – | 4.80-j3.00 | – | Ohms |

(1) Class AB
(2) Class A

FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC

**For PNP test circuit, reverse all polarities.**




| | | | | | |
|---|---|---|---|---|---|
| C1,C2,C4 | 170–780 pF, ARCO 469 | R2 | 10 Ω, 5 Watt | L3 | 10 μH Molded Choke |
| C3 | 25–280 pF, ARCO 464 | R3,R4 | 1 kΩ, 1/4 Watt | L4 | 15 Turns, #24 AWG Enamaled Wire, Closewound on a 100 Ω, 1 Watt Carbon Resistor. |
| C5,C6 | 500 μF, 3 V, ELECTROLYTIC | R5,R6 | 10 kΩ, 1/4 Watt | | |
| C7,C9 | 0.1 μF, Disc Ceramic | CR1,CR2 | 1N4001 | | |
| C8 | 1000 pF Disc Ceramic | L1 | 3 Turns, #18 AWG, 1/4" I.D., 3/16" Long | L5 | FERROXCUBE VK200 – 20/4B |
| C10,C11 | 100 μF, 15 V, ELECTROLYTIC | L2 | 3 Turns, #16 AWG, 3/8" I.D., 1/4" Long | | |
| R1 | 10 Ω, 1/2 Watt | | | | |

MOTOROLA Semiconductor Products Inc.

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# MRF454
# MRF454A

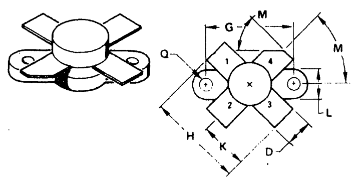
## The RF Line

**80 W – 30 MHz**
**RF POWER TRANSISTORS**
**NPN SILICON**

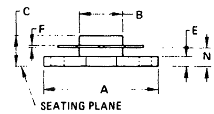
### NPN SILICON RF POWER TRANSISTORS

. . . designed for power amplifier applications in industrial, commercial and amateur radio equipment to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 80 Watts
  Minimum Gain = 12 dB
  Efficiency = 50%



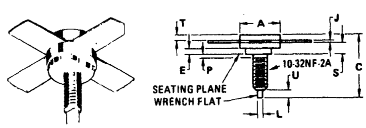

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

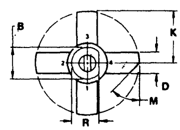



| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 24 64 | 24.89 | 0.970 | 0.980 |
| B | 11.81 | 12.95 | 0.465 | 0.510 |
| C | 5.82 | 6.98 | 0.229 | 0.275 |
| D | 5.46 | 5.97 | 0.216 | 0.235 |
| E | 2.13 | 2.79 | 0.084 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 11.05 | – | 0.435 | – |
| L | 6.22 | 6.48 | 0.246 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.66 | 4.52 | 0.144 | 0.178 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |

CASE 211-11

MRF454




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-10

MRF454A

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 25 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 45 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 20 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 250<br>1.43 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | –65° to +200° | °C |

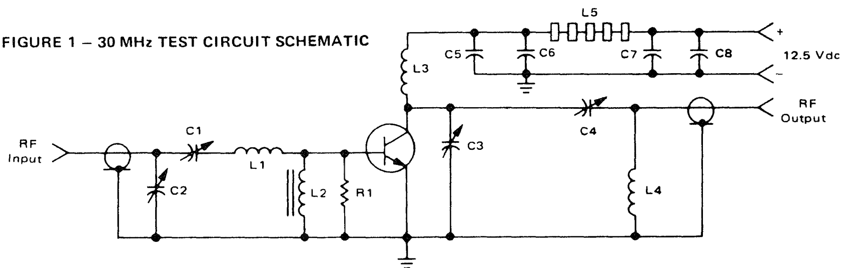
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.7 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 250 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | $G_{pe}$ | 12 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | $\eta$ | 50 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | $Z_{in}$ | – | .938–j.341 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | $Z_{out}$ | – | 1.16–j.201 | – | Ohms |
| Parallel Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | – | – | 1.06 Ω 1817 pF | – | – |
| Parallel Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 W, f = 30 MHz) | – | – | 1.19 Ω 777 pF | – | – |

FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1, C2, C4 | ARCO 469 | L1 | 3 Turns, #18 AWG, 5/16" I.D., 5/16" Long |
| C3 | ARCO 466 | L2 | VK200 – 20/4B, FERROXCUBE |
| C5 | 1000 pF, UNELCO | L3 | 12 Turns, #18 AWG Enameled Wire, 1/4" I.D., Close Wound |
| C6, C7 | 0.1 μF Disk Ceramic | L4 | 3 Turns 1/8" O.D. Copper Tubing, 3/8" I.D., 3/4" Long |
| C8 | 1000 μF/15 V Electrolytic | L5 | 7 FERRITE Beads, FERROXCUBE #56-590-65/3B |
| R1 | 10 Ohm/1 Watt, Carbon | | |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

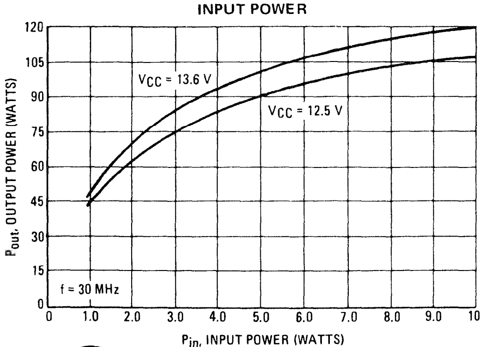
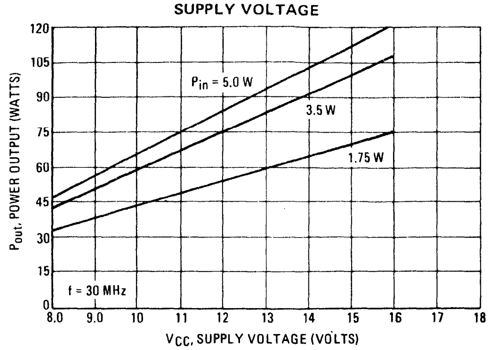



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE



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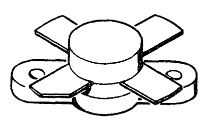
# MRF460

## The RF Line

40 W (PEP) – 30 MHz

RF POWER
TRANSISTOR

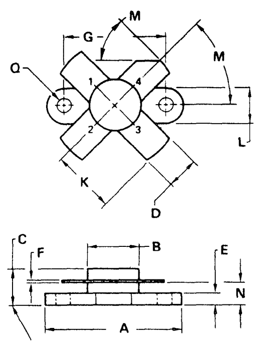
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 40 W (PEP)
  Minimum Gain = 12 dB
  Efficiency = 40%
- Intermodulation Distortion at Rated Power Output –
  IMD = -30 dB (Max)
- Isothermal-Resistor Design Results in Rugged Device
- Replacement for 2N6368




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 11.81 | 12.95 | 0.465 | 0.510 |
| C | 5.82 | 6.98 | 0.229 | 0.275 |
| D | 5.46 | 5.97 | 0.216 | 0.235 |
| E | 2.13 | 2.79 | 0.084 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 11.05 | – | 0.435 | – |
| L | 6.22 | 6.48 | 0.246 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.66 | 4.52 | 0.144 | 0.178 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |

CASE 211-11

### MAXIMUM RATINGS

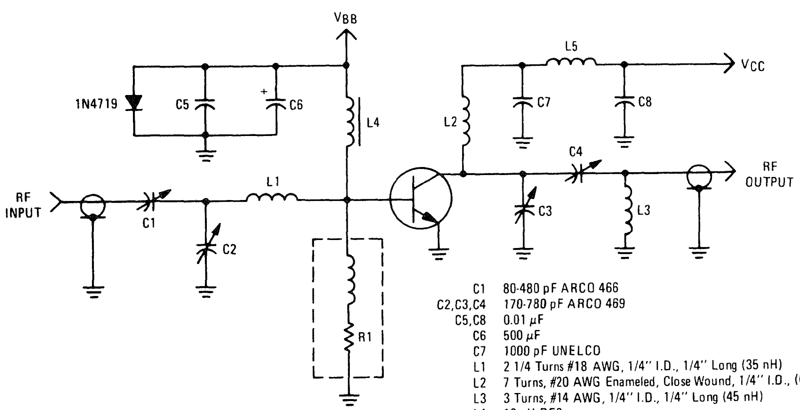
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 15 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 175<br>1.0 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

***ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 12.5 Vdc, $V_{BE}$ = 0, $T_C = +55^oC$) | $I_{CES}$ | – | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 40 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 300 | 350 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 40 W (PEP), $I_C$ = 4.7 Adc Max, $V_{CC}$ = 12.5 Vdc, $I_{CQ}$ = 50 mAdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 12 | 15 | – | dB |
| Intermodulation Distortion Ratio (Figure 1) ($P_{out}$ = 40 W (PEP), $I_C$ = 4.7 Adc Max, $V_{CC}$ = 12.5 Vdc, $I_{CQ}$ = 50 mAdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -35 | -30 | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 40 W (PEP), $I_C$ = 4.7 Adc Max, $V_{CC}$ = 12.5 Vdc, $I_{CQ}$ = 50 mAdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 40 | 45 | – | % |

*Indicates JEDEC Registered Data.

**FIGURE 1 – 30 MHz TEST CIRCUIT**




C1 80-480 pF ARCO 466
C2,C3,C4 170-780 pF ARCO 469
C5,C8 0.01 μF
C6 500 μF
C7 1000 pF UNELCO
L1 2 1/4 Turns #18 AWG, 1/4" I.D., 1/4" Long (35 nH)
L2 7 Turns, #20 AWG Enameled, Close Wound, 1/4" I.D., (0.2 μH)
L3 3 Turns, #14 AWG, 1/4" I.D., 1/4" Long (45 nH)
L4 10 μH RFC
L5 RF Choke Ferroxcube VK200-20-4B
R1 10 Ohms, Wirewound, 1 W (0.25 μH Inductance)

FIGURE 2 — OUTPUT POWER versus INPUT POWER

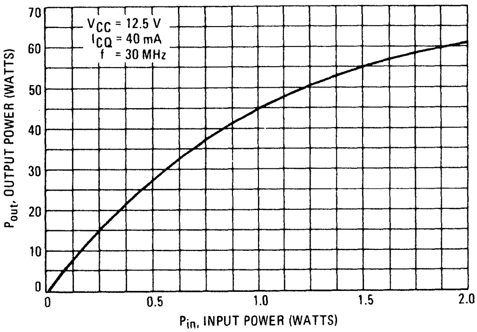



FIGURE 3 — POWER GAIN versus FREQUENCY

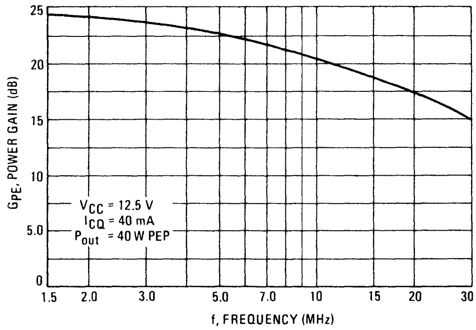



FIGURE 4 — INTERMODULATION DISTORTION versus OUTPUT POWER

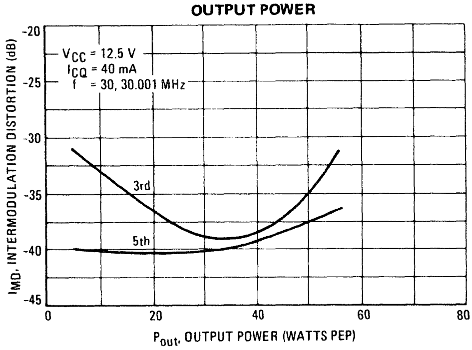



FIGURE 5 — OUTPUT POWER versus SUPPLY VOLTAGE

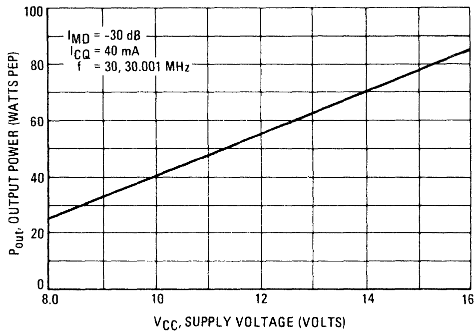



FIGURE 6 — OUTPUT RESISTANCE versus FREQUENCY

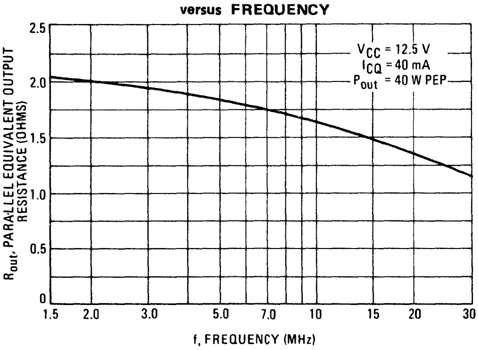



FIGURE 7 — OUTPUT CAPACITANCE versus FREQUENCY

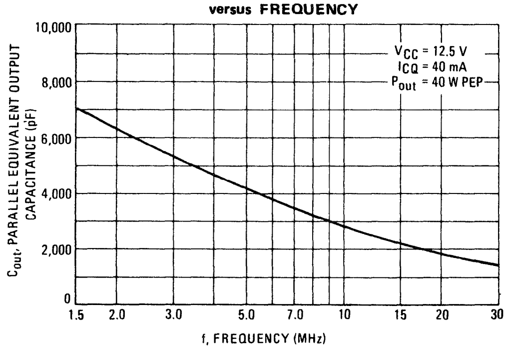


**FIGURE 8 – DC SAFE OPERATING AREA**

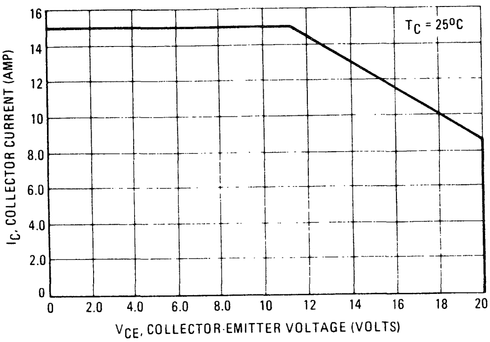
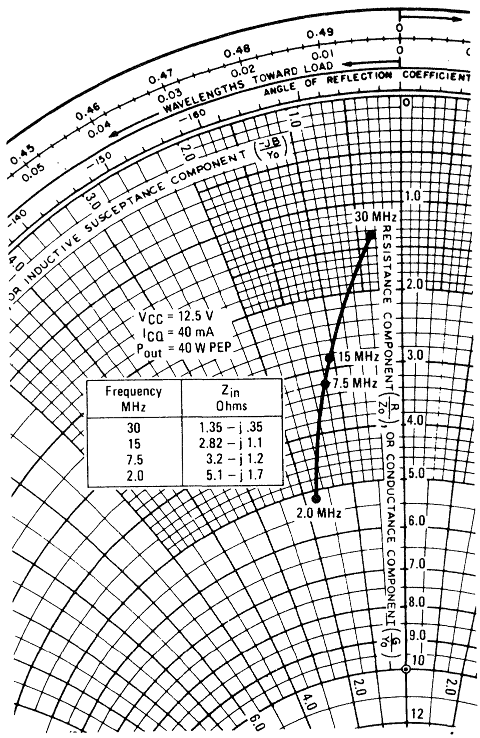



**FIGURE 9 – SERIES EQUIVALENT IMPEDANCE**




| Frequency MHz | $Z_{in}$ Ohms |
|---|---|
| 30 | 1.35 – j .35 |
| 15 | 2.82 – j 1.1 |
| 7.5 | 3.2 – j 1.2 |
| 2.0 | 5.1 – j 1.7 |

## MATCHING PROCEDURE

In the push-pull circuit configuration two device parameters are critical for optimum circuit performance. These parameters are $V_{BE(on)}$ and $h_{FE}$. Both parameters can be guaranteed by measuring $I_{CQ}$ of the devices and selecting pairs with a $\Delta I_{CQ} \leqslant 10$ mAdc.

Actual $I_{CQ}$ matching is performed in the MRF460 test circuit with a $V_{CE}$ equal to 28 Volts. The base bias supply is adjusted to set $I_{CQ}$ equal to 40 mAdc using a reference standard MRF460. The production MRF460s are tested and categorized in ranges of 10 mAdc. Finally, the devices are stocked as pairs with a guaranteed $\Delta I_{CQ} \leqslant 10$ mAdc.

## APPLICATIONS INFORMATION

The MRF460 transistor is designed for linear power amplifier operation in the HF region (2 to 30 MHz). It features guaranteed linear amplifier performance rather than the conventional performance demonstrated in a class C* amplifier.

Class C operation is inherently non-linear, but in many power amplifier applications non-linear operation does not present major problems. With a single frequency driving signal, the only spurious signals generated are harmonics and these can be supressed in the amplifier tuned networks and output filter.

For single sideband (SSB), low level amplitude modulation (AM), and other types of complex signals, class C operation is generally not satisfactory. For instance, when a signal contains multiple frequencies at close spacings, odd-order non-linearities will generate spurious outputs which are within the passband of the tuned circuits and filters; therefore, the spurious outputs are not suppressed before they reach the antenna or other load. As a result, such complex signals require linear amplification if the amplified signal is to be free of spurious outputs.

A detailed analysis of spurious signals generated by non-linearities and linearity requirements of various applications is described in Chapter 12 of Reference 1.

The following discussion concerns itself with a detailed description of the MRF460 characterization curves and general information on solid-state linear power amplifier design.

*"Class C", as used here refers to operation with the no signal conditions $I_C = 0$, and $V_{BE} = 0$, and a theoretical conduction angle of less than $180^o$, even though the actual conduction angle may be more than $180^o$.

### The Two-Tone Test

The MRF460 functional test specifications consist of a linear power amplifier test with guaranteed limits on power output, gain, efficiency, and intermodulation distortion (IMD) output levels. A two-tone test signal is used with the test amplifier as shown in Figure 1.

The two-tone test is one of many methods commonly used for testing linear amplifier performance. This test involves driving the amplifier with two RF signals, of equal amplitude, separated in frequency from each other by approximately 1 kHz.

## APPLICATIONS INFORMATION (continued)

When a two-tone test signal consisting of frequencies $f_1$ and $f_2$ is passed through a non-linear amplifier, odd order non-linearities generate spurious signals near the desired carrier. The level of these spurious signals provides a measure of the degree of non-linearity of the amplifier. This type of non-linearity is called intermodulation distortion (IMD). The spurious signals generated by IMD are further classified according to the exponential order of the amplifier non-linearity, i.e., 3rd order IMD products, 5th order IMD products, etc. The 3rd and 5th order IMD products are usually the most significant encountered with linear power amplifiers. Data on both 3rd and 5th order IMD are included in the MRF460 characterization.

Third order IMD generates spurious signals near the operating frequency at frequencies $2f_1 - f_2$ and $2f_2 - f_1$; and 5th order IMD spurious are at frequencies $3f_1 - 2f_2$ and $3f_2 - 2f_1$.

### Specifications and Characterization

The two-tone functional amplifier test is performed in a manner identical to the conventional class C functional test with two exceptions: a two-frequency signal is used in place of a single frequency, and amplifier linearity is added to the items tested and specified.

The functional test procedure for the MRF460 requires driving the test amplifier with a two-frequency signal and measuring power output, gain, efficiency, and linearity.

Power output, gain and efficiency measurement methods are the same for both linear and class C amplifier.

Since a multiple frequency test signal has an instantaneous power level which varies with time, power levels are normally expressed in peak envelope power (PEP). This is the average power level of the envelope at its greatest amplitude point.

When the test signal consists of multiple signals with equal amplitudes and different frequencies, the relationship of average power and PEP is given by the following expression:

$$\text{Average power} = \frac{\text{PEP}}{N}$$

where N = the number of input frequencies.

Therefore, when measuring the power level of a standard two-tone test signal, a true average reading power meter will indicate 1/2 the PEP of the signal.

Linearity is tested by measuring the amplitudes of the 3rd and 5th order IMD products. The ratio of one of the 3rd order products to one of the two desired frequencies is then expressed as a power ratio in decibels (dB). This is repeated for the 5th order products. The smaller of these two ratios (usually the 3rd order) is then included in the electrical characteristics specifications as intermodulation distortion ratio (IMD).

### MRF460 Performance Curves

Figures 2 and 3 show typical power output and gain characteristics versus frequency and/or input power. These curves are similar to those found on other RF power transistor data sheets with one exception, a two-frequency test signal was used rather than a single frequency signal.

The curves shown in Figure 4 are unique to transistors characterized for linear power amplifier service and show the typical IMD levels versus power output.

The MRF460 features guaranteed IMD performance at the -30 dB level. However, the designer may desire IMD greater or less than -30 dB for a particular application. Figure 4 provides data on IMD levels that can be expected as a function of output power.

Figure 5 reflects the power output that can be obtained at a fixed IMD ratio for operation with dc supply voltages other than 12.5 Vdc.

Figures 6 and 7 show the large signal impedance characteristics of the MRF460. These are similar to curves shown on other Motorola data sheets except a two-frequency test signal was used rather than a single frequency signal.

It must be stressed that the data shown in Figures 6 and 7 do not represent y, z, h, s, or any standard two-port parameter set. The actual transistor impedance levels during normal operation in a power amplifier are given. For a detailed discussion of RF power transistor large signal impedance, see Reference 2.

### Linear Amplifier Design

The following is a discussion of some general design considerations for solid-state linear power amplifiers. While this is not a detailed analysis of linear amplifier design, some general guidelines are provided.

The major difference between linear power amplifiers and class C power amplifiers is in the dc bias circuitry. As stated in the introduction, class C operation usually involves a collector dc supply as the only bias voltage with $V_E = V_B = 0$. The collector current is zero until the input RF signal turns the transistor "on."

In contrast, a linear amplifier is normally operated with forward bias and some collector current flowing when no signal is present.

The magnitude of no-signal collector current and the bias circuitry may vary with the application. Optimum no-signal collector current for the MRF460 was found to be approximately 50 mA.

The key to bias circuitry for good linearity lies in maintaining the base-emitter dc voltage relatively constant as the RF signal amplitude varies. The inherent nature of a forward-biased RF power transistor is to bias itself "off" with increasing RF drive signal. Therefore, a constant voltage source is required for base voltage.

Temperature effects also complicate the situation, since $V_{BE}$ decreases with increasing temperature.

A simple solution to the bias problem involves the use of a forward-biased diode mounted on the transistor heat sink for thermal coupling to the transistor. A sample of this technique is shown in the test circuit of Figure 1. The reader is referred to reference 3 for a detailed description of the operation of this bias circuit. It is also possible to use complex active circuitry for biasing, and some rather exotic schemes have been developed to provide the same results.

Another important consideration is the collector-output network. Normally, a network with low impedance to ground for harmonics provides better linearity than a network with high harmonic impedances; therefore, some experimentation with network configuration is in order. Proper impedance matching remains the primary factor in both input and output network design. Further, it must also be stressed that the collector load impedance should be designed for the PEP, not the average power output. See Chapter 13 of Reference 1 for a detailed discussion of network design considerations.

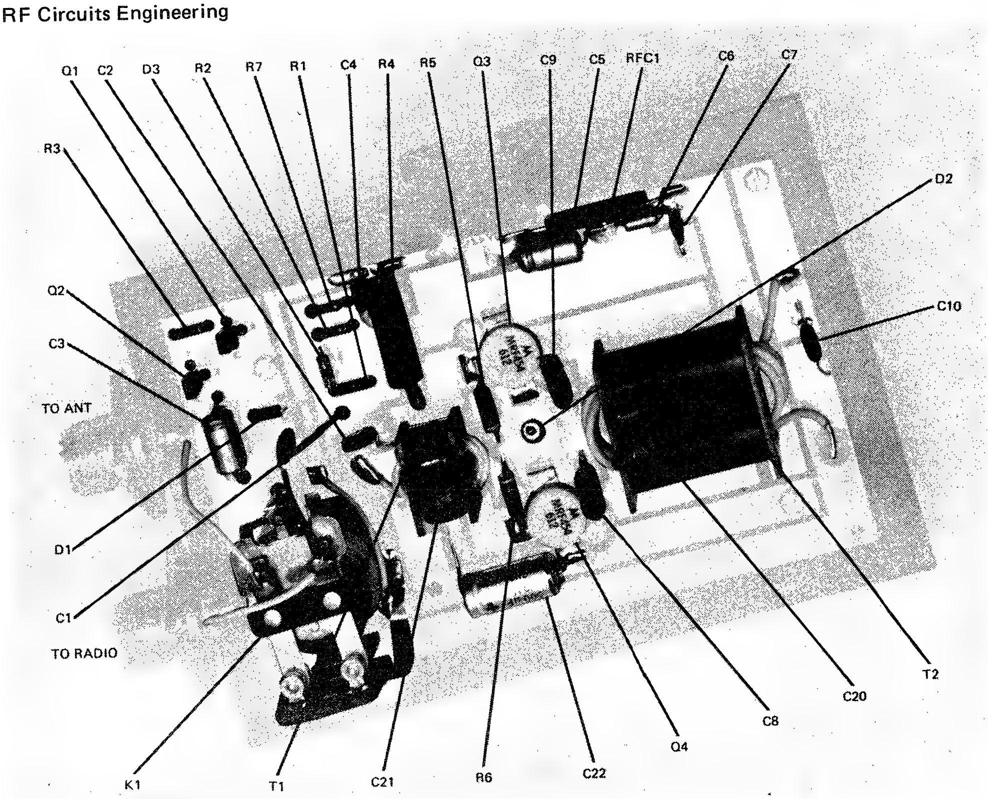
Feedback may also be employed to improve linearity and may take the form of either neutralization or negative RF feedback. The possibilities here are limited only by the designer's imagination. Of course, negative RF feedback involves a decrease in gain to improve linearity.

### REFERENCES

1. Pappenfus, Bruene, Schoenike, "Single Sideband Principles and Circuits", McGraw-Hill.
2. Hejhall, "Systemizing RF Power Amplifier Design", Motorola Semiconductor Products Inc., Application Note AN-282A.

# 140W (PEP) Amateur Radio Linear Amplifier 2-30MHz

*Prepared by:*
**Tom Bishop**
RF Circuits Engineering




The popularity of 2-30 MHz, SSB, Solid State, linear amplifiers is increasing in the amateur market. This EB describes an inexpensive, easy to construct amplifier and some pertinent performance information. The amplifier uses two MRF454 devices. These transistors are specified at 80 Watts power output with 5 Watts of input drive, 30 MHz, and 12.5 Vdc. The MRF454 is used because it is a readily available device and has the high saturation power and ruggedness desired for this application. This device is not characterized for SSB. However, IMD specs for the amplifier are shown in Figures 2 and 3.

## THE AMPLIFIER

The performance of the amplifier can be seen in figures 1, 2, 3, 5, 6, 7 and 8. The quiescent current is 500 mA on each device. This amount of bias was needed to prevent "cross over" at the higher output powers during SSB operation. The amplifier operates across the 2-30 MHz band with relatively flat gain response and reaches gain saturation at approximately 210 Watts of output power. Figure 5 depicts the amplitude modulated waveform with respect to a 100-Watt carrier. Figure 6 depicts the increased amplitude modulation at 50-Watt carrier. In both cases the peak output power is equal to approximately 210 Watts due to the saturation of the MRF454. The 50-Watt carrier is thus recommended in any amplitude modulated applications.

The bias diode D2 has been mounted in the heatsink for temperature tracking. The cathode is pressed into the heatsink and the anode extends through the circuit board. (See figure 9.) Both input and output transformers are 4:1 turns ratio (16:1 impedance ratio) to achieve low input SWR across the specified band and a high saturation capability. T1* is made from FairRite Products, ferrite beads, material #77, .375" O.D. x .187/.200" I.D. x .44L". T2* is made from Stackpole Co. ferrite sleeves #57-0503-7D.

When using this design, it is important to interconnect the ground plane on the bottom of the board to the top; especially at the emitters of the MRF454s. Eyelets were used in this design, which are easier to apply, but #18 AWG wire can be used. On the photomask, (see figure 10) ":" signifies where the ground plane has been interconnected. The letter "O" designates where the 4-40 screws are installed to fasten the board to the heatsink. 6-32 nuts are used as spacers on the 4-40 screws between the board and the heatsink to keep the board from touching the heatsink.

## THE DESIGN

This amplifier was designed for simplicity. The design goal was to allow repeatability of assembly and reduce the number of components used. The amplifier will accept Single Side Band or Amplitude Modulation without external switching. A carrier operated relay circuit is on the same layout to make this an easy amplifier to add on to any suitable radio with an RF output of 1.0-5.0 Watts. All components used are readily available at most distributors and are relatively inexpensive.

NOTE: Similarly assembled transformers can be purchased from:

**Communications Power, Inc.**
2407 Charleston Road
Mountain View, CA 94043
(415) 965-2623

**M-RED – C&L**
1475 Oakdale
Pasadena, CA 91106

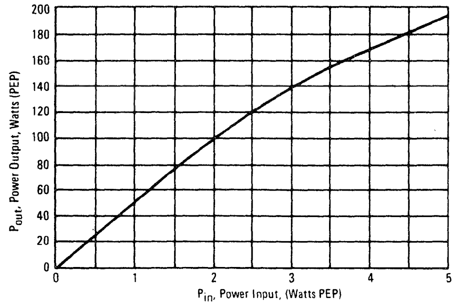



**FIGURE 1—$P_{out}$ vs. $P_{in}$, 30 MHz, 13.6 Vdc**

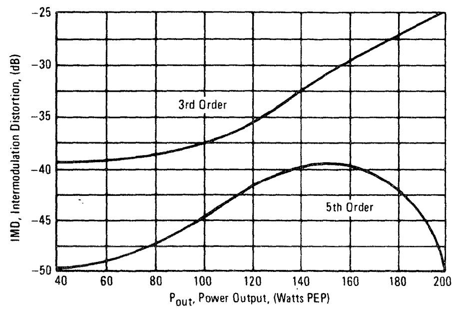



**FIGURE 2—Intermodulation Distortion Versus $P_{out}$, 30 MHz, 13.6 Vdc**

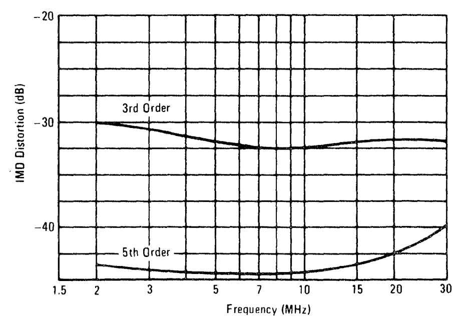
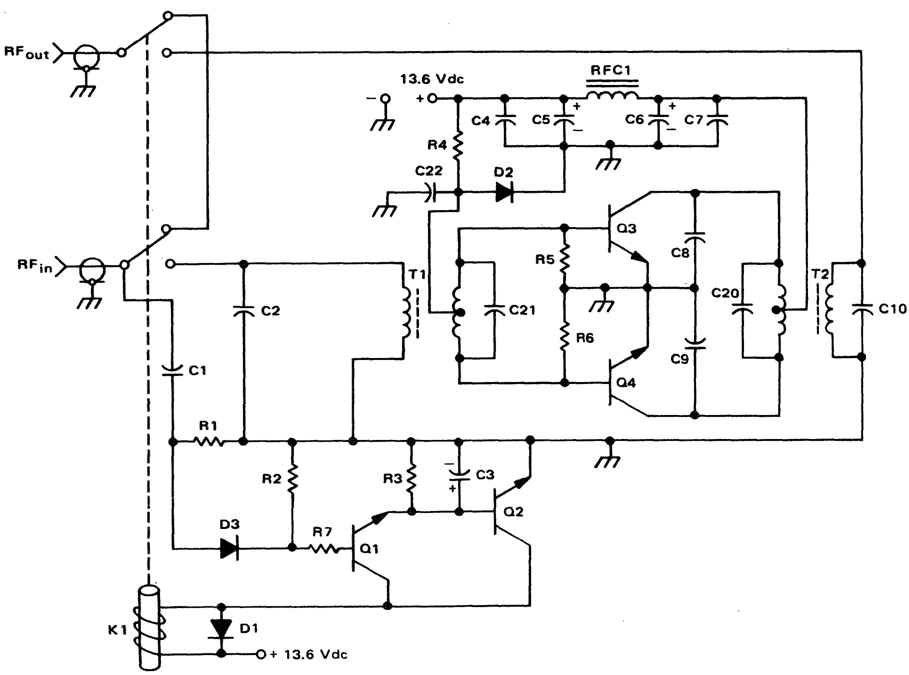


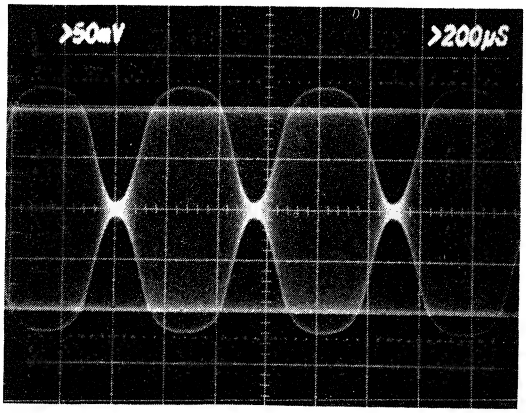

**FIGURE 3—IMD vs. Frequency, $P_{out}$ = 140 Watt PEP, 13.6 Vdc**

*Ref: Application Notes
AN749 BroadBand Transformers and Power Combining Techniques for RF – H. Granberg
AN762 Linear Amplifiers for Mobile Operation – H. Granberg



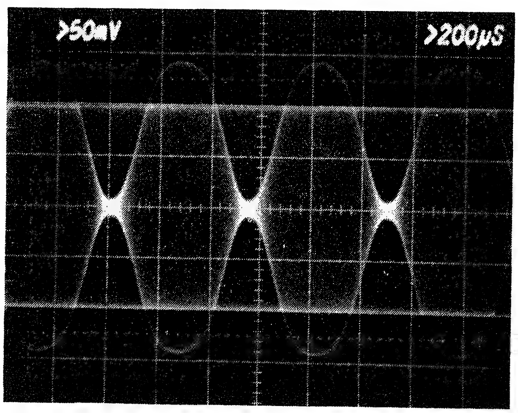

| | | |
|---|---|---|
| C1 | = | 33 pF Dipped Mica |
| C2 | = | 18 pF Dipped Mica |
| C3 | = | 10 μF 35 Vdc for AM operation, |
| | | 100 μF 35 Vdc for SSB operation. |
| C4 | = | .1 μF Erie |
| C5 | = | 10 μF 35 Vdc Electrolytic |
| C6 | = | 1 μF Tantalum |
| C7 | = | .001 μF Erie Disc |
| C8, 9 | = | 330 pF Dipped Mica |
| R1 | = | 100 kΩ 1/4 W Resistor |
| R2, 3 | = | 10 kΩ 1/4 W Resistor |
| R4 | = | 33 Ω 5 W Wire Wound Resistor |
| R5, 6 | = | 10 Ω 1/2 W Resistor |
| R7 | = | 100 Ω 1/4 W Resistor |
| RFC1 | = | 9 Ferroxcube Beads on #18 AWG Wire |
| D1 | = | 1N4001 |
| D2 | = | 1N4997 |
| D3 | = | 1N914 |
| Q1, Q2 | = | 2N4401 |
| Q3, 4 | = | MRF454 |
| T1, T2 | = | 16:1 Transformers |
| C20 | = | 910 pF Dipped Mica |
| C21 | = | 1100 pF Dipped Mica |
| C10 | = | 24 pF Dipped Mica |
| C22 | = | 500 μF 3 Vdc Electrolytic |
| K1 | = | Potter & Brumfield KT11A 12 Vdc Relay or Equivalent |

**FIGURE 4—Schematic Diagram**



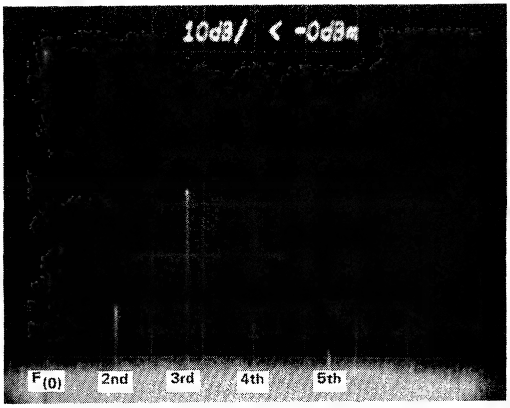

Amplitude Modulated Waveform with Superimposed Carrier. Carrier Conditions: $f = 30$ MHz; $P_{in} = 2.2$ Watts; $P_{out} = 100$ Watts (carrier); $V_{CC} = 13.6$ Vdc

**FIGURE 5**



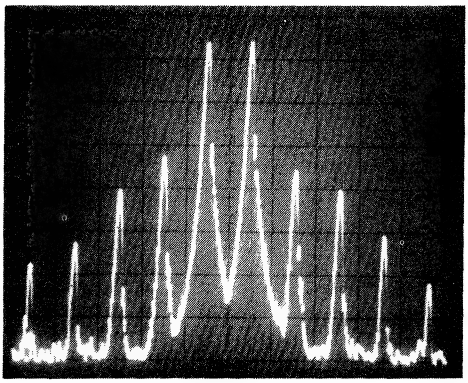

Amplitude Modulated Waveform with Superimposed Carrier. Carrier Conditions: $f = 30$ MHz; $P_{in} = 1.3$ Watt; $P_{out} = 50$ Watts; $V_{CC} = 13.6$ Vdc

**FIGURE 6**




Frequency Spectrum, 30 MHz ($F_{(0)}$, 2nd, 3rd, and 5th harmonics are visible). Vertical resolution: 10 dB/div. Horizontal 20MHz/div.

**FIGURE 7**



INTERMODULATION DISTORTION, 30, 30.001 MHz (3rd, 5th, 7th, 9th) order distortion products are visible. Vertical resolution: 10 dB/div. Horizontal: 1KHz/div.

**FIGURE 8**

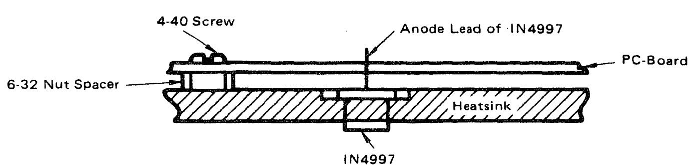



**FIGURE 9 – Mounting Detail of IN4997 and 6-32 Nut (Spacer)**

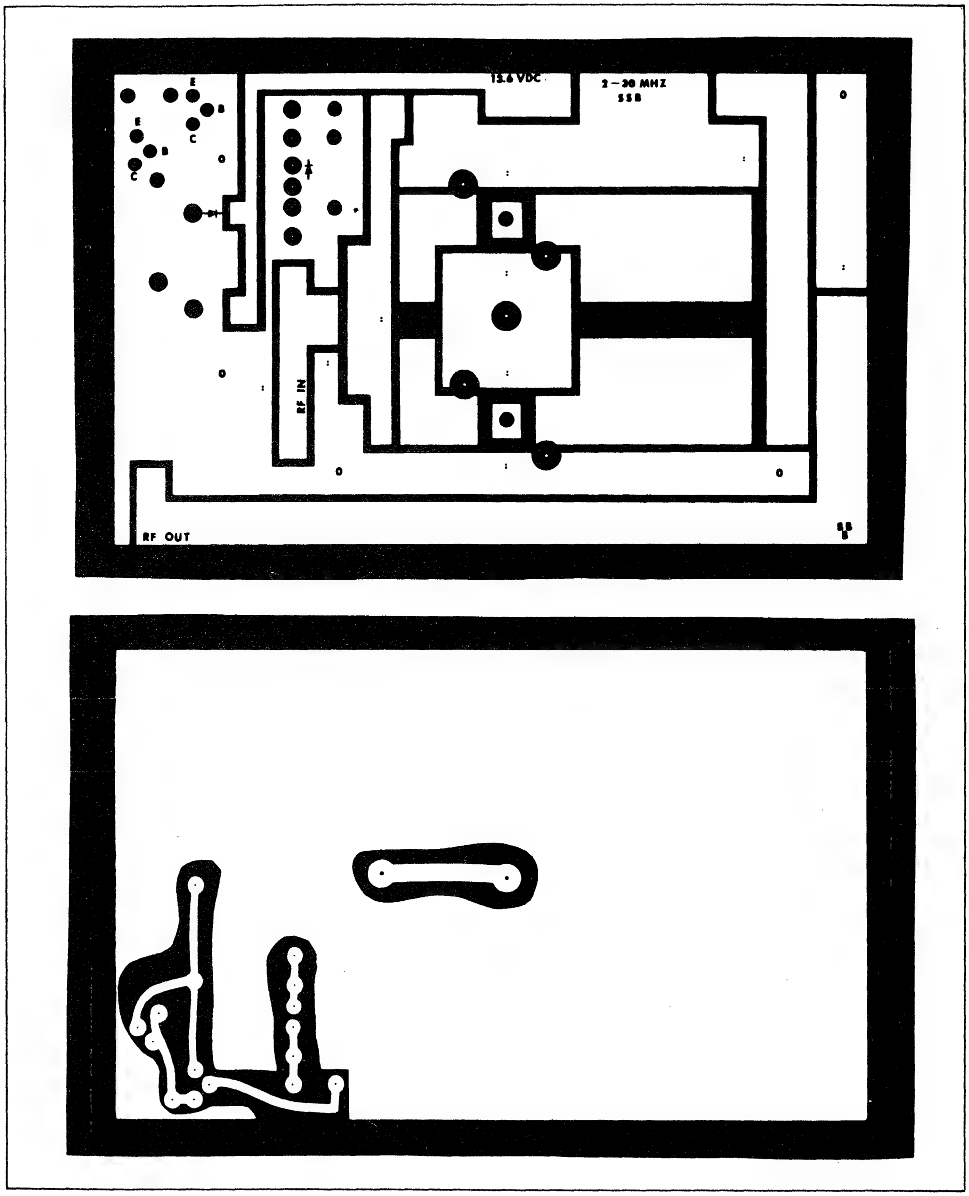



**FIGURE 10— Photomaster (Positive)**

Note: The use of this amplifier is illegal for Class D Citizen Band service.

# LINEAR AMPLIFIERS FOR MOBILE OPERATIONS

Prepared by:
**Helge Granberg**

## INTRODUCTION

The three versions of the amplifier described here are intended mainly for amateur radio applications, but are suitable for other applications such as marine radio with slight modifications.

100 W is obtained with two MRF453's. (A similar device is available as HEP S3037.) MRF460 is also adaptable to this design, resulting in approximately 1.0 to 1.5 dB higher overall power gain than the values shown. The MRF454 devices which can be directly substituted with MRF465's for slightly lower IMD, deliver the 140 W, and two MRF421 devices are used in the 180 W version.

The use of chip capacitors results in good repeatability, making the overall design suitable for mass production.

There are several precautions and design hints to be taken into consideration regarding transistor amplifiers:

1. Eliminate circuit oscillation. Oscillations may cause overdissipation of the device or exceed the breakdown voltages.
2. Limit the power supply current to prevent excessive dissipation.
3. Adopt protective circuitry, such as fast acting ALC.
4. Ensure proper attachment of the device to a heatsink using Silicone grease (such as Corning 340 or GC Electronics 8101) to fill all thermal gaps.

## THE TRANSISTORS

The MRF421 with a specified power output of 100 W PEP or CW is the largest of the three RF devices. The maximum dissipation limit is 290 Watts, which means that the continuous collector current could go as high as 21.3 A at 13.6 V operated into any load. The data sheet specifies 20 A; this is actually limited by the current carrying capability of the internal bonding wires. The values given are valid at a 25°C mount temperature.

The minimum recommended collector idling current in Class AB is 150 mA. This can be exceeded at the expense of collector efficiency, or the device can be operated in Class A at an idling current of approximately one fourth the maximum specified collector current. This rule of thumb applies to most RF power transistors, although not specified for Class A operation.

The MRF454 is specified for a power output of 70 W CW. Although the data sheet does not give broadband performance or IMD figures, typical distortion products are ≈ -31 to -33 dB below one of the two test tones (7) with a 13.6 V supply. This device has the highest figure of merit (ratio of emitter periphery and base area), which correlates with the highest power gain.

The maximum dissipation is 180 Watts, and the maximum continuous collector current is 15 A. The minimum recommended collector idling current is 100 mA, and like the MRF421, can be operated in Class A.

The MRF453 has the lowest figure of merit, but due to the lower power specification, its gain exceeds that of the MRF421. This power gain is caused by the lower currents incorporated within the transistor package, and reduced circuit construction difficulties for low voltage operation.

At a power level of 180 Watts and 13.6 V, the peak currents approach 30 A, and every 100 mV lost in the emitter grounding or collector dc feed have a significant effect in the peak power capability. The minimum collector idling current for the MRF453 is recommended as 40 mA for Class AB, but can be operated at 3 A for Class A.

It should be noted that the data sheet figures for power gain and linearity are lowered when the device is used in multi-octave broadband circuit. Normally the device input and output impedances vary by at least a factor of three from 1.6 to 30 MHz. Therefore, when impedance correction networks are employed, some of the power gain and linearity must be sacrificed.

The input correction network can be designed with RC or RLC combinations to give better than 1 dB gain flatness across the band with low input VSWR. In a low-voltage system, little can be done about the output without reducing the maximum available voltage swing.

## THE BASIC CIRCUIT

Figure 1 shows the basic circuit of the linear amplifier. For different power levels and devices, the impedance ratios of T1 and T3 will be different and the values of R1, R2, R3, R4, R5, C1, C2, C3, C4 and C6 will have to be changed.

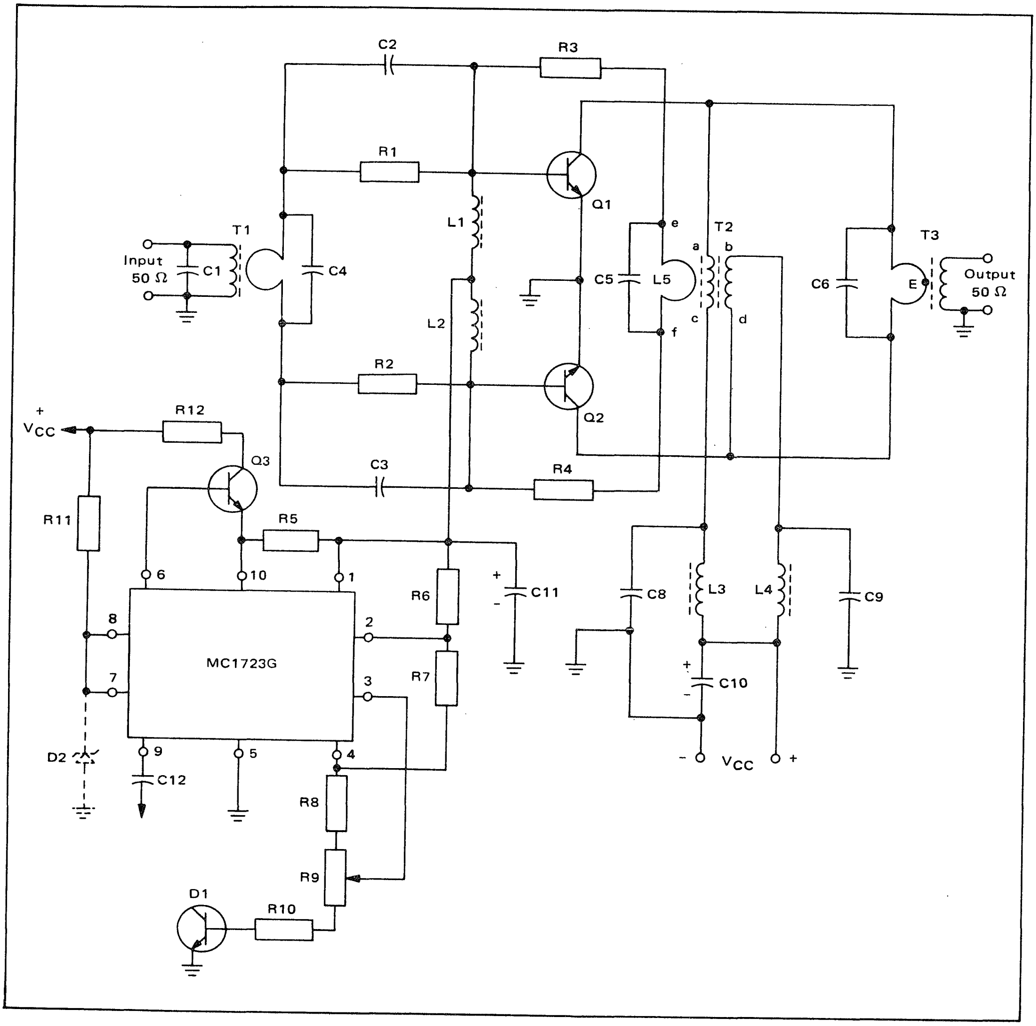



FIGURE 1 — Basic Circuit of Linear Amplifier

### The Bias Voltage Source

The bias voltage source uses active components (MC1723G and Q3) rather than the clamping diode system as seen in some designs. The advantages are line voltage regulation capability, low stand-by current, (≷1.0 mA) and wide range of voltage adjustability. With the component values shown, the bias voltage is adjustable from 0.5 to 0.9 Volts, which is sufficient from Class B to Class A operating conditions.

In Class B the bias voltage is equal to the transistor $V_{BE}$, and there is no collector idling current present (except small collector-emitter leakage, $I_{CES}$), and the conduction angle is 180°.

In Class A the bias is adjusted for a collector idling current of approximately one-half of the peak current in actual operating conditions, and the conduction angle is 360°.

In Class AB, (common for SSB amplifiers) the bias is set for a low collector quiescent current, and the conduction angle is usually somewhat higher than 180°.

The required base bias current can be approximated as:

$$\frac{I_C}{h_{FE}},$$

where:

$I_C$ = Collector current, assuming an efficiency of 50%

and $P_{out}$ of 180 W is: $\frac{2P_{out}}{V_{CC}} = \frac{360}{13.6} = 26.47$ A.

$h_{FE}$ = Transistor dc beta (typical 30, from data sheet)

$$\text{Bias current} = \frac{26.47}{30} = 0.88 \text{ A}$$

R12 shares the dissipation with Q3, and its value must be such that the collector voltage never drops below approximately 2.0 V (e.g. $\frac{(13.6-2)}{0.88} = 13.2\ \Omega$). The MRF421 devices used for this design had $h_{FE}$ values on the high side (45), and R12 was calculated as 20Ω, which is also sufficient for the lower power versions.

R5 determines the current limiting characteristics of the MC1723, and 0.5 Ω will set the limiting point to 1.35 A, ± 10%.

For SSB operation, excluding two-tone testing, the duty cycle is low, and the energy charged in C11 can supply higher peak bias currents than required for 180 W PEP.

It is possible to operate the basic regulator circuit, MC1723, at lower output voltages than specified, with modified component values, at a cost of reduced line and output voltage regulation tolerances which are still more than adequate for this application. Temperature sensing diode D1 is added for bias tracking with the RF power transistors. The base-emitter junction of a 2N5190 or similar device can be used for this purpose. The temperature tracking within 15% to 60°C is achieved, even though the die processing is quite different from that of the RF transistors. The physical dimensions of Case 77 (2N5190) permits its use for the center stand-off of the circuit board.

The measured output voltage variations of the bias source from zero to 1.0 A were ± 8-12 mV resulting in a source impedance of ≈ 30 mΩ.

**The Input Frequency Correction Network**

The input correction network consists of R1, R2, C2 and C3. With the combination of the negative feedback derived from L5 through R3 and R4 (Figure 1), it forms an attenuator with frequency selective characteristics. At 30 MHz the input power loss is 1-2 dB, increasing to 10-12 dB at 1.6 MHz. This compensates the gain variations of the RF transistors over the 1.6 to 30 MHz band, resulting in an overall gain flatness of approximately ±1.0 to ±1.5 dB.

Normally an input VSWR of 2.0:1 or lower (Figure 8) is possible with this type of input network (considered sufficient for most applications). More sophisticated LRC networks will yield slightly better VSWR figures, but are more complex and sometimes require individual adjustments.

Additional information on designing and optimizing these networks can be found in reference[2].

**The Broadband Transformers**

The input transformer T1 and the output transformer T3 are of the same basic type, with the low impedance winding consisting of two pieces of metal tubing, electrically shorted in one end and the opposite ends being the connections of this winding (Figure 3A). The multiturn high impedance winding is threaded through the tubing so that the low and high impedance winding connections are in opposite ends of the transformer.

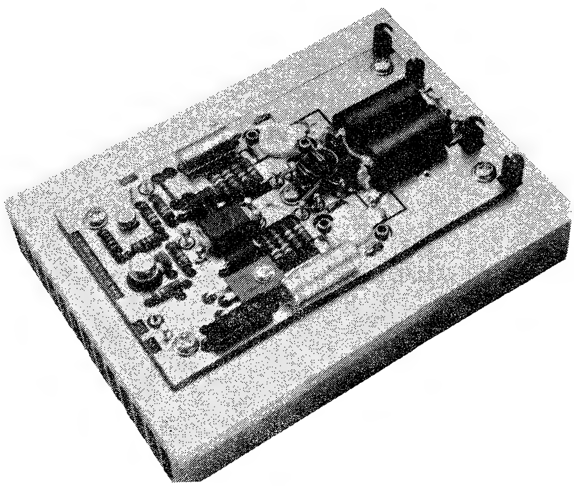
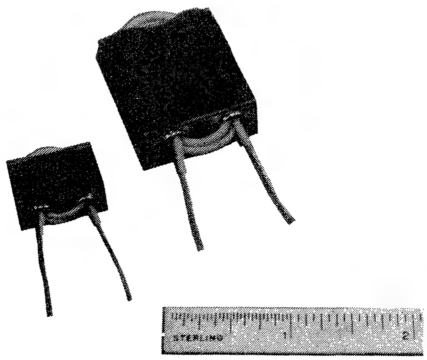
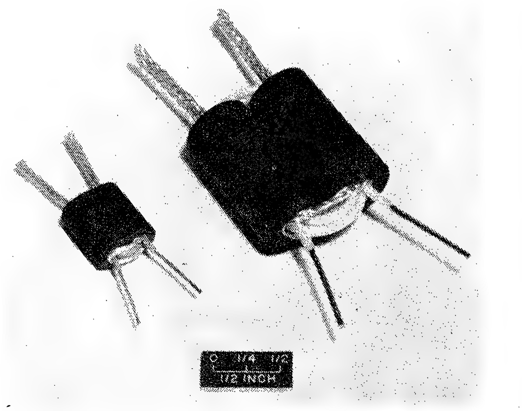


FIGURE 2 — Photograph of 180 W Version of the Linear Amplifier




A.




B.

**FIGURE 3 – Two Variations of the Input and Output Transformers (T1 and T3)**

The physical configuration can be implemented in various manners. A simplified design can be seen in Figure 3B. Here the metal tubing is substituted with copper braid, obtained from any co-axial cable of the proper diameter (4). The coupling coefficient between the primary and secondary windings is determined by the length-to-diameter ratio of the metal tubing or braid, and the gauge and insulation thickness of the wire used for the high impedance winding. For high impedance ratios (36:1 and higher), miniature co-axial cable where only the braid is used, leaving the inner conductor disconnected gives the best results. The high coefficient of coupling is important only at the high-frequency end of the band, e.g. 20 to 30 MHz. Additional information on these transformers can be found in reference (5).

Both transformers are loaded with ferrite material to provide sufficient low-frequency response. The minimum required inductance in the one turn winding can be calculated as:

$$L = \frac{R}{2\Pi f}$$

where
L = Inductance in $\mu$H
R = Base-to-Base or Collector-to-Collector Impedance
f = Lowest Frequency in MHz

For example, in the 180 Watt version the input transformer is of 16:1 impedance ratio, making the secondary impedance 3.13 Ω with a 50 Ω interface.

$$\text{Then: } L = \frac{3.13}{6.28 \times 1.6} = 0.31\ \mu H$$

For the output transformer having a 25:1 impedance ratio to a 50 Ω interface, $L = \frac{2}{6.28 \times 1.6} = 0.20\ \mu H$.

It should be noted that in the lower power versions, where the input and output impedances are higher and the transformers have lower impedance ratios, the required minimum inductances are also higher.

T2, the collector choke supplying the dc to each collector, also provides an artificial center tap for T3. This combination functions as a real center tapped transformer with even harmonic cancellation. T2 provides a convenient low impedance source for the negative feedback voltage, which is derived from a separate one turn winding.

T3 alone does not have a true ac center tap, as there is virtually no magnetic coupling between its two halves. If the collector dc feed is done through point E (Figure 1) without T2, the IMD or power gain is not affected, but the even harmonic suppression may be reduced by as much as 10 dB at the lower frequencies.

The characteristic impedance of ac and bd (T2) should equal the collector-to-collector impedance but is not critical, and for physical convenience a bifilar winding is recommended.

The center tap of T2 is actually bc (Figure 1), but for stabilization purposes, b and c are separated by RF chokes by-passed individually by C8 and C9.

**TABLE 1 — Parts List**

| | 100 W AMPLIFIER | 140 W AMPLIFIER | 180 W AMPLIFIER |
|---|---|---|---|
| C1 | 51 pF | 51 pF | 82 pF |
| C2, C3 | 5600 pF | 5600 pF | 6800 pF |
| C4 | — | 390 pF | 1000 pF |
| C5 | 680 pF | 680 pF | 680 pF |
| C6 | 1620 pF (2 x 470 pF chips + 680 pF dipped mica in parallel) | 1760 pF (2 x 470 pF chips + 820 pF dipped mica in parallel) | 1940 pF (2 x 470 pF chips + 1000 pF dipped mica in parallel) |
| C8,C9 | 0.68 μF | 0.68 μF | 0.68 μF |
| C10 | 100 μF/20 V electrolytic | 100 μF/20 V electrolytic | 100 μF/20 V electrolytic |
| C11 | 500 μF/3 V electrolytic | 500 μF/3 V electrolytic | 500 μF/3 V electrolytic |
| C12 | 1000 pF disc ceramic | 1000 pF disc ceramic | 1000 pF disc ceramic |
| R1, R2 | 2 x 3.9 Ω/½ W in parallel | 2 x 3.6 Ω/½ W in parallel | 2 x 3.3 Ω/½ W inparallel |
| R3, R4 | 2 x 4.7 Ω/½ W in parallel | 2 x 5.6 Ω/½ W in parallel | 2 x 3.9 Ω/½ W inparallel |
| R5 | 1.0 Ω/½ W | 0.5 Ω/½ W | 0.5 Ω/½ W |
| R6 | 1.0 kΩ/½ W | 1.0 kΩ/½ W | 1.0 kΩ/½ W |
| R7 | 18 kΩ/½ W | 18 kΩ/½ W | 18 kΩ/½ W |
| R8 | 8.2 kΩ/½ W | 8.2 kΩ/½ W | 8.2 kΩ/½ W |
| R9 | 1.0 kΩ trimpot | 1.0 kΩ trimpot | 1.0 kΩ trimpot |
| R10 | 150 Ω/½ W | 150 Ω/½ W | 150 Ω/½ W |
| R11 | 1.0 kΩ/½ W | 1.0 kΩ/½ W | 1.0 kΩ/½ W |
| R12 | 20 Ω/5 W | 20 Ω/5 W | 20 Ω/5 W |
| L1, L2 | Ferroxcube VK200 19/4B ferrite choke | | |
| L3, L4 | Two Fair-Rite Products ferrite beads 2673021801 or equivalent on AWG #16 wire each. | | |
| L5 | 1 separate turn through toroid of T2. | | |
| T1 | 9:1 (3:1 turns ratio) | 9:1 (3:1 turns ratio) | 16:1 (4:1 turns ratio) |
| | Ferrite core: Stackpole 57-1845-24B, Fair-Rite Products 2873000201 or two Fair-Rite Products 0.375" OD x 0.200" ID x 0.400", Material 77 beads for type A (Figure 3) transformer. See text. | | |
| T2 | 6 turns of AWG #18 enameled, bifilar wire | | |
| | Ferrite core: Stackpole 57-9322, Indiana General F627-8 Q1 or equivalent. | | |
| T3 | 16:1 (4:1 turns ratio) | 16:1 (4:1 turns ratio) | 25:1 (5:1 turns ratio) |
| | Ferrite core: 2 Stackpole 57-3238 ferrite sleeves (7D material) or number of toroids with similar magnetic characteristics and 0.175" sq. total cross sectional area. See text. | | |
| | All capacitors except C12, part of C5 and the electrolytics are ceramic chips. Values over 82 pF are Union Carbide type 1225 or Varadyne size 14. Others are type 1813 or size 18 respectively. | | |
| Q1, Q2 | MRF453 | MRF454 | MRF421 |
| Q3 | | 2N5989 or equivalent | |
| D1 | | 2N5190 or equivalent | |
| D2 | | Not Used | |
| | c. | b. | a. |
| | Dotted line in performance data. | Dashed line in performance data. | Solid line in performance data. |

## GENERAL DESIGN CONSIDERATIONS

As the primary and secondary windings of T3 are electrically isolated, the collector dc blocking capacitors (which may also function as low-frequency compensation elements) have been omitted. This decreases the loss in RF voltage between the collectors and the transformer primary, where every 100 mV amounts to approximately 2 W in output power at 180 W level. The RF currents at the collectors operating into a 2Ω load are extremely high, e.g.: $I_{RF} = \sqrt{\frac{180}{2.0}} = 9.5$ A, or peak $\frac{9.5}{0.707} = 13.45$ A.

Similarly, the resistive losses in the collector dc voltage path should be minimized. From the layout diagram of the lower side of the circuit board (Figure 4), $V_{CC}$ is brought through two 1/4" wide runs, one on each side of the board. With the standard 1.0 oz. laminate, the copper thickness is 1.4 thousands of an inch, and their combined cross sectional area would be equivalent to AWG #20 wire. This is not adequate to carry the dc collector current which under worst case conditions can be over 25 A. Therefore, the high power version of this design requires 2 oz. or heavier copper laminate, or these runs should be reinforced with parallel wires of sufficient gauge.

The thermal design (determining the size and type of a heat sink required) can be accomplished with information in the device data sheet and formulas presented in references 5 and 6. As an example, with the 180 W unit using MRF421's, the Junction-to-Ambient Temperature

$(R_{\theta JA})$ is calculated first as $R_{\theta JA} = \frac{T_J - T_A}{P}$ where:

$T_J$ = Maximum Allowed Junction Temperature (150°C).
$T_A$ = Ambient Temperature (40°C).

$P$ = Dissipated Power $(\frac{180}{\eta}) \times (100 - \eta)$

$\eta$ = Collector Efficiency (%).

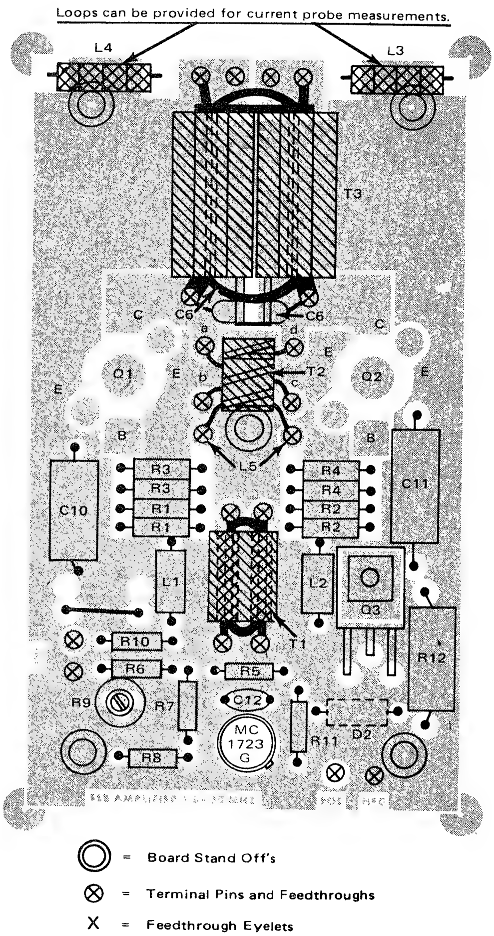
If the worst case efficiency at 180 W CW is 55%, then

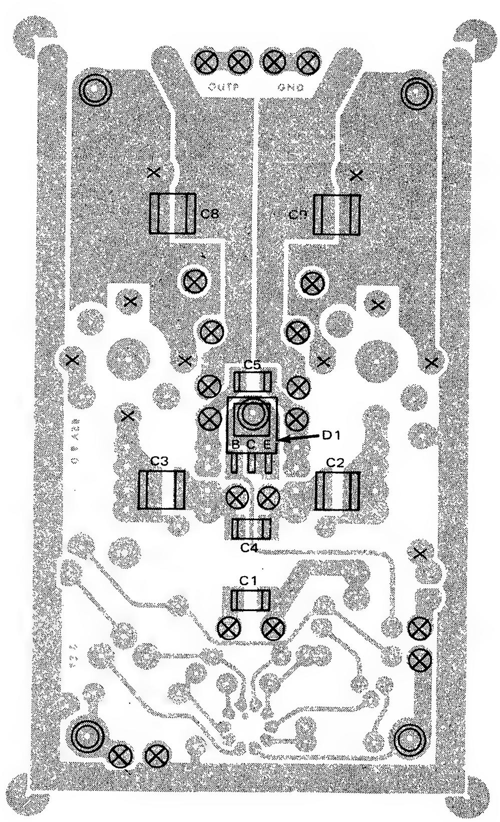
$P$ = 148 W, and $R_{\theta JA} = \frac{150 - 40}{(\frac{148}{2})} = 1.49°$ C/W (for one device). The Heat Sink-to-Ambient Thermal Resistance, $R_{\theta SA} = R_{\theta JA} - (R_{\theta JC} + R_{\theta CS})$ where: $R_{\theta JC}$ = Device Junction-to-Case Thermal Resistance, 0.60°C/W* (from data sheet).

$R_{\theta CS}$ = Thermal Resistance, Case-to-Heat Sink, 0.1°C/W (from table in reference 5).

Then: $R_{\theta SA} = \frac{1.49 - (0.60 + 0.1)}{2} = 0.395°$ C/W

This number can be used to select a suitable heat sink for the amplifier. The information is given by most manufacturers for their standard heat sinks, or specific lengths of extrusion. As an example, a 9.1" length of thermalloy 6153 or a 7.6" length of Aavid Engineering 60140 extrusion would be required for 100% duty cycle, unless the air velocity is increased by a fan or other means.




The $R_{\theta JC}$ figure of 0.875°C/W given for the MRF421 is in error, and will be corrected in the future prints of the data sheet.

**FIGURE 4 – Component Layout of the Basic Amplifier**

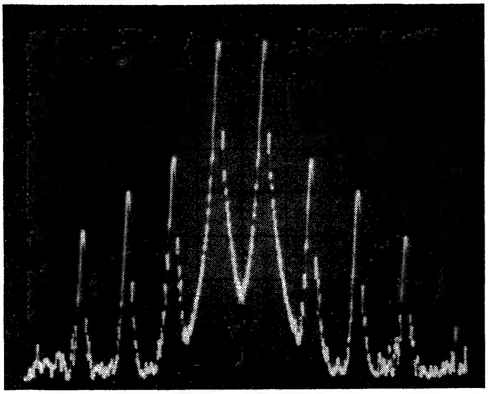


**FIGURE 5 – An Example of the IMD Spectral Display (c. Power Output = 180 W PEP, 30.00 MHz)**

**The Two Tones Have Been Adjusted 6 dB Below the Top Line, and the Distortion Products Relative to Peak Power can be Directly Read on the Scale.**

## PERFORMANCE AND MEASUREMENTS

The performance of each amplifier was measured with equipment similar to what is described in reference (2). The solid lines in Figures 6, 7, 8 and 9 represent the 100 W unit, the dashed lines represent the 140 W unit, and the dotted lines refer to the 180 W version. The data presented is typical, and spreads in the transistor $h_{FE}$'s will result in slight variations in RF power gain (Figure 7).

The performance data is also affected by the purity of the driving source. There should be at least 5–6 dB IMD margin to the expected power amplifier specification, and a harmonic suppression of 50 dB minimum below the fundamental is recommended (7)..

The IMD measurements were done in accordance to the E.I.A. proposed standard, commonly employed in Ham Radio and other commercial equipment design. The distortion products are referenced to the peak power, and adjusting the tone peaks 6 dB below the 0 dB line on the spectrum analyzer screen (Figure 5) provides a direct reading on the scale.

The collector efficency under two tone test conditions is normally 15 – 20% lower than at CW. The load line has been optimized for the peak power (as well as possible in a broadband system with transformer impedance ratios of 4:1, 9:1, 16:1, 25:1, etc. available), which at SSB represents a smaller duty cycle, and the power output varies between zero and maximum. Typical figures are 40 – 45% and 55 – 65% respectively.

The stability and load mismatch susceptibility were tested at 15 and 30 MHz employing an LC network (2) to simulate high and low reactive loads at different phase angles. The maximum degree of load mismatch was controlled by placing high power 50-Ohm attenuators between the amplfiier output and variable LC network.

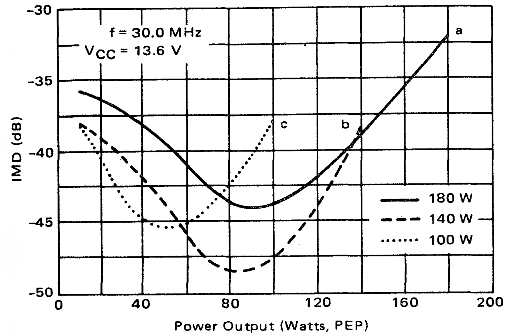



**FIGURE 6 – Intermodulation Distortion versus Power Output**

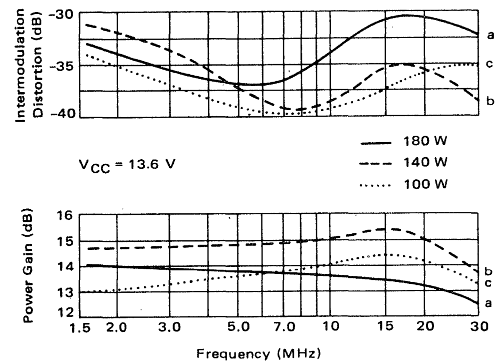



**FIGURE 7 – IMD and Power Gain versus Frequency**

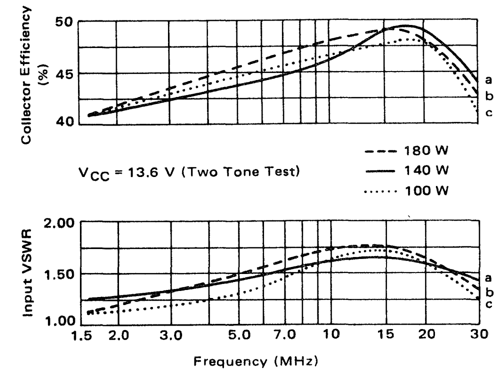



**FIGURE 8 – Input VSWR and Collector Efficiency versus Frequency**

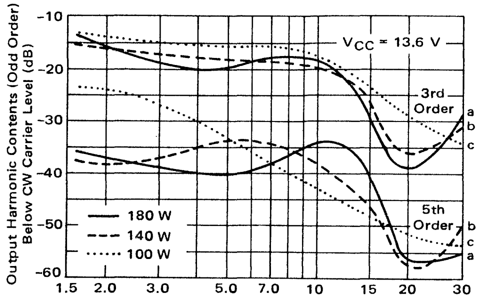



**FIGURE 9 — Output Harmonic Contents (Odd Order) versus Frequency**

A 2 dB attenuator limits the output VSWR to 4.5:1, 3 dB to 3.0:1, 6 dB to 1.8:1 etc., assuming that the simulator is capable of infinite VSWR at some phase angle. The attenuators for -1.0 dB or less were constructed of a length of RG-58A co-axial cable, which at 30 MHz has an attenuation of 3.0 dB/100 ft. and at 15 MHz 2.0 dB/100 ft. Combinations of the cable and the resistive attenuators can be used to give various degrees of total attenuation.

The tests indicated the 100 W and 140 W amplifiers to be stable to 5:1 output VSWR at all phase angles, and the 180 W unit is stable to 9:1. All units passed a load mismatch test at full rated CW power at an output load mismatch of 30:1, which they were subjected to, until the heat sink temperature reached 60°C. For this, the load mismatch simulator was motor driven with a 2 second cycle period.

### Output Filtering

Depending on the application, harmonic suppression of -40 dB to -60 dB may be required. This is best accomplished with low-pass filters, which (to cover the entire range) should have cutoff frequencies (e.g. 35 MHz, 25 MHz, 15 MHz, 10 MHz, 5.5 MHz and 2.5 MHz).

The theoretical aspect of low-pass filter design is well covered in the literature (8).

A simple Chebyshev type constant K, 2 pole filter (Figure 10) is sufficient for 40 – 45 dB output harmonic suppression.

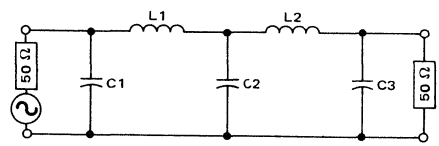



**FIGURE 10**

The filter is actually a dual pi-network, with each pole introducing a -90° phase shift at the cutoff frequency, where L1, L2, C1 and C3 should have a reactance of 50 Ohms, and C2 should be 25 Ohms. If C2 is shorted, the resonances of L1C1 and L2C3 can be checked with a grid-dip meter or similar instrument for their resonant frequencies.

The calculated attenuation for this filter is 6.0 dB per element/octave, or -45 dB for the 3rd harmonic. In practice, only -35 to -40 dB was measured, but this was due to the low Q values of the inductors (approximately 50). Air core inductors give excellent results, but toroids of magnetic materials such as Micrometals grade 6 are also suitable at frequencies below 10 MHz. Dipped mica capacitors can be used throughout.

If the filters are correctly designed and the component tolerances are 5% or better, the power loss will be less than 1.0 dB.

### SUMMARY

The basic circuit layout (Figure 1) has been successfully adopted by several equipment manufacturers. Minor modifications may be necessary depending on the availability of specific components. For instance, the ceramic chip capacitors may vary in physical size between various brands, and recent experiments show that values > 0.001 μF can be substituted with unencapsulated polycarbonate stacked-foil capacitors. These capacitors are available from Siemens Corporation (type B32540) and other sources. Also T1 and T2 can be constructed from stacks of ferrite toroids with similar material characteristics. Toroids are normally stock items, and are available from most ferrite suppliers.

The above is primarily intended to give an example of the device performance in non-laboratory conditions, thus eliminating the adjustments from unit to unit.

### REFERENCES:


1. Hejhall R.: *Understanding Transistor Response Parameters,* AN-139A Motorola Semiconductor Products Inc..
2. Granberg, H.: *A Two Stage 1 kW Solid-State Linear Amplifier,* AN-758 Motorola Semiconductor Products, Inc..
3. Granberg, H.: *Get 300 W PEP Linear Across 2 to 30 MHz From This Push-Pull Amplifier,* EB-27 Motorola Semiconductor Products Inc..
4. Granberg, H.: *Broadband Transformers and Power Combining Techniques for RF,* AN-749 Motorola Semiconductor Products Inc..
5. White, John: Thermal Design of Transistor Circuits, *QST,* April 1972, pp. 30-34.
6. *Mounting Stripline-Opposed-Emitter (SOE) Transistors,* AN-555 Motorola Semiconductor Products Inc..
7. Granberg, H.: *Measuring the Intermodulation Distortion of Linear Amplifiers,* EB-38 Motorola Semiconductor Products Inc..
8. *Reference Data for Radio Engineers,* ITT, Howard & Sams Co., Inc.

# LOW DISTORTION 1.6 TO 30 MHz SSB DRIVER DESIGNS

Prepared by:
**Helge O. Granberg**

## GENERAL CONSIDERATION

Two of the most important factors to be considered in broadband linear amplifier design are the distortion and the output harmonic rejection.

The major cause for intermodulation distortion is amplitude nonlinearity in the active element. The nonlinearity generates harmonics, and the fundamental odd-order products are defined as $2f1-f2$, $2f2-f1$, $3f2-2f2$, $3f2-2f1$, etc., when a two-tone test signal is used. These harmonics may not always appear in the amplifier output due to filtering and cancellation effects, but are generated within the active device. The amplitude and harmonic distortion cannot really be distinguished, except in a case of a cascaded system, where even-order products in each stage can produce odd-order products through mixing processes that fall in the fundamental region.[2] This, combined with phase distortion – which in practical circuits is more apparent at higher frequencies – can make the distortion analysis extremely difficult;[5,2] whereas, if only amplitude distortion was present, the effect of IMD in each stage could easily be calculated.

In order to expect a low harmonic output of the power amplifier, it is also important for the driving source to be harmonic-free. This is difficult in a four-octave bandwidth system, even at 10-20 watt power levels. Class A biasing helps the situation, and Class A push-pull yields even better results due to the automatic rejection of even harmonics.

Depending on the application, a full Class A system is not always feasible because of its low efficiency. The theoretical maximum is 50%, but practical figures are not higher than 25% to 35%. It is sometimes advantageous to select a bias point somewhere between Class AB and A which would give sufficiently good results, since filtering is required in the power amplifier output in most instances anyway.

In order to withstand the high level of steady dc bias current, Class A requires a much larger transistor die than Class B or AB for a specific power output. There are sophisticated methods such as generating the bias voltage from rectified RF input power, making the dc bias proportional to the drive level.[1] This also yields to a better efficiency.

## 20 W, 25 dB AMPLIFIER WITH LOW-COST PLASTIC DEVICES

The amplifier described here provides a total power gain of about 25 dB, and the construction technique allows the use of inexpensive components throughout. The plastic RF power transistors, MRF475 and MRF476, featured in this amplifier, were initially developed for the CB market. The high manufacturing volume of these TO-220 packaged parts makes them ideal for applications up to 50 MHz, where low cost is an important factor.

The MRF476 is specified as a 3-watt device and the MRF475 has an output power of 12 watts. Both are extremely tolerant to overdrive and load mismatches, even under CW conditions. Typical IMD numbers are better than -35 dB, and power gains are 18 dB and 12 dB, respectively, at 30 MHz.

The collectors of the transistors are electrically connected to the TO-220 package mounting tab which must be isolated from the ground with proper mounting hardware (TO-220 AB) or by floating heat dissipators. The latter method, employing Thermalloy 6107 and 6106 heat dissipators, was adapted for this design. Without an airflow, the 6106 and 6107 provide sufficient heat sinking for about 30% duty cycle in the CW mode. Collector idle currents of 20 mA are recommended for both devices, but they were increased to 100 mA for the MRF475 and to 40 mA for the MRF476 to reduce the higher order IMD products and to achieve better harmonic suppression.

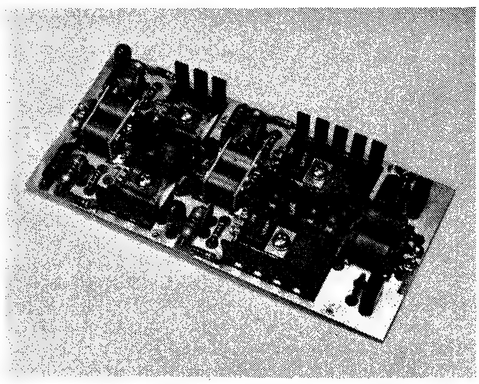


FIGURE 1

### Biasing and Feedback

The biasing is achieved with the well-known clamping diode arrangement (Figure 2). Each stage has it own diode, resistor, and bypass network, and the diodes are mounted between the heat dissipators, being in physical contact with them for temperature-tracking purposes. A better thermal contact is achieved through the use of silicone grease in these junctions.

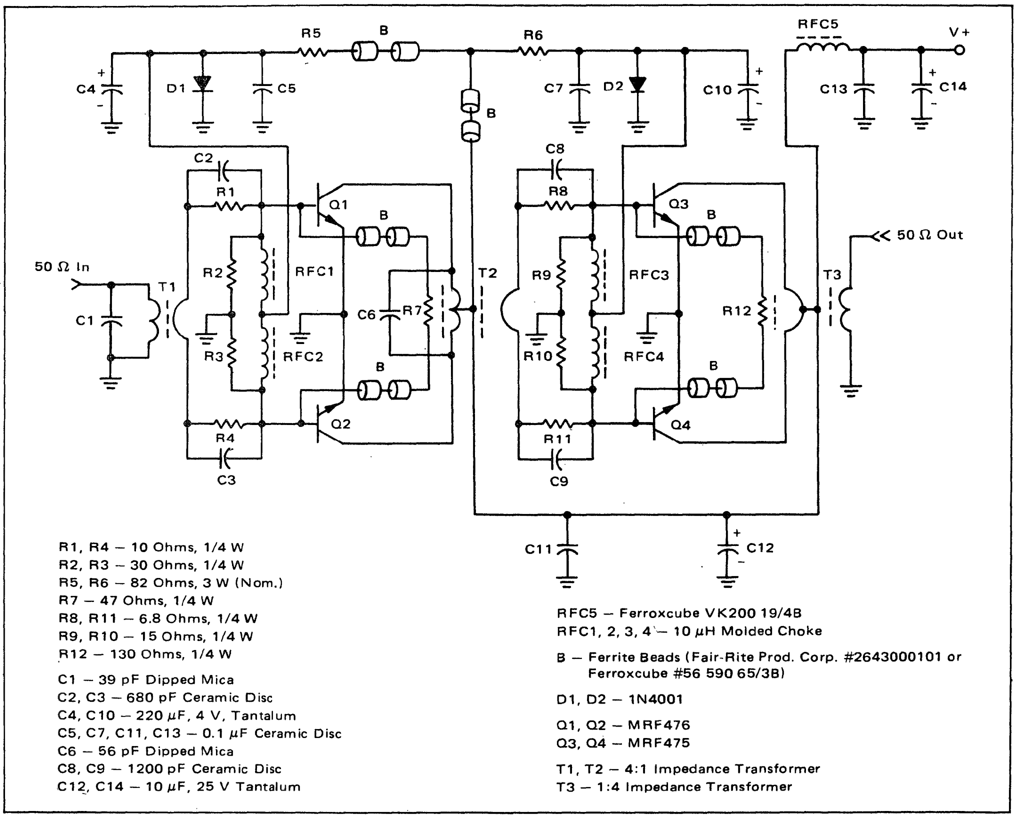



**FIGURE 2**

The bias currents of each stage are individually adjustable with R5 and R6. Capacitors C4 and C10 function as audio-frequency bypasses to further reduce the source impedance at the frequencies of modulation.

This biasing arrangement is only practical in low and medium power amplifiers, since the minimum current required through the diode must exceed $I_C/h_{fe}$.

Gain leveling across the band is achieved with simple RC networks in series with the bases, in conjunction with negative feedback. The amplitude of the out-of-phase voltages at the bases is inversely proportional to the frequency as a result of the series inductance in the feedback loop and the increasing input impedance of the transistors at low frequencies. Conversely, the negative feedback lowers the effective input impedance presented to the source (not the input impedance of the device itself) and with proper voltage slope would equalize it. With this technique, it is possible to maintain an input VSWR of 1.5:1 or less from 1.6 to 30 MHz.

### Impedance Matching and Transformers

Matching of the input and output impedances to 50 ohms, as well as the interstage matching, is accomplished with broadband transformers (Figures 3 and 4).

Normally only impedance ratios such as 1:1, 4:1, 9:1, etc., are possible with this technique, where the low-impedance winding consists of metal tubes, through which an appropriate number of turns of wire is threaded to form the high-impedance winding. To improve the broadband characteristics, the winding inductance is increased with magnetic material. An advantage of this design is its suitability for large-quantity manufacturing, but it is difficult to find low-loss ferrites with sufficiently high permeabilities for applications where the physical size must be kept small and impedance levels are relatively high. Problems were encountered especially with the output transformer design, where an inductance of 4 μH minimum is required in the one-turn winding across the collectors, when the load impedance is

$$\frac{2(V_{CE} - V_{CEsat})^2}{P_{out}} = \frac{2(13.6 - 2.5)^2}{20} = 12.3 \text{ ohms.}^{4,8}$$

Ferrites having sufficiently low-loss factors at 30 MHz range only up to 800–1000 in permeability and the inductance is limited to 2.5–3.0 μH in the physical size required. This would also limit the operation to approximately 4 MHz, below which excessive harmonics are

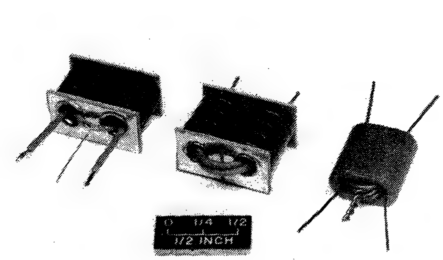



**FIGURE 3**

**Examples of broadband transformers. Variations of these are used in all designs of this article (see text). All ferrites in transformers are Fair-Rite Products Corp. #2643006301 ferrite beads.* The turns ratios shown in Figure 4 are imaginary and do not necessarily lead to correct design practices.**

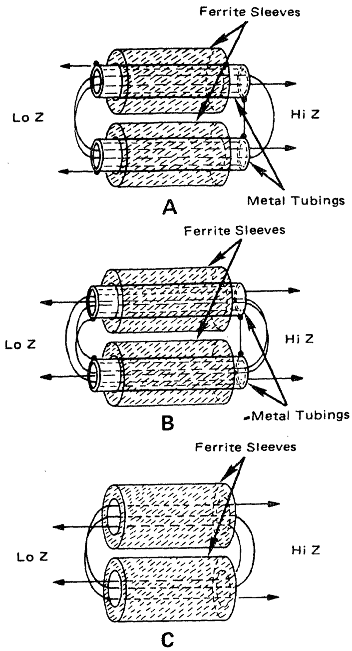



**FIGURE 4**

generated and the efficiency will degrade. One possible solution is to increase the number of turns, either by using the metal tubes for only part of the windings as in Figure 4B, or simply by winding the two sets of windings randomly through ferrite sleeves or a series of beads (Figures 3C and 4C). In the latter, the metal tubes can be disregarded or can be used only for mounting purposes. T3 was eventually replaced with a transformer of this type, although not shown in Figure 1.

Below approximately 100 MHz, the input impedances of devices of the size of MRF475 and smaller are usually capacitive in reactance, and the $X_S$ is much smaller than the $R_S$, (Low Q). For practical purposes, we can then use the formula $\sqrt{(R_S^2 + X_S^2)}$ to find the actual input impedance of the device. The data-sheet numbers for 30 MHz are 4.5, -j2.4 ohms, and we get $\sqrt{(4.5^2 + 2.4^2)}$ = 5.1 ohms. The base-to-base impedance in a push-pull circuit would be four times the base-to-emitter impedance of one transistor. However, in Class AB, where the base-emitter junction is forward biased and the conduction angle is increased, the impedance becomes closer to twice that of one device. The rounded number of 11 ohms must then be matched to the driver output. The drive power required with the 10 dB specified minimum gain is

$$P_{out}/\text{Log}^{-1}(G_{PE}/10) = 2.0\text{ W}$$

and the driver output impedance using the previous formula is $2(11.1^2)/2$ = 123 ohms. The 11 ohms in series with the gain-leveling networks (C8, R8 and C9, R11) is 17 ohms. The closest practical transformer for this interface would be one with 9:1 impedance ratio. This would present a higher-than-calculated load impedance to the driver collectors, and for the best linearity the output load should be lower than required for the optimum gain and efficiency. Considering that the device input impedance increases at lower frequencies, a better overall match is possible with a 4:1, especially since the negative feedback is limited to only 4 dB at 2 MHz due to its effect on the efficiency and linearity.

The maximum amount of feedback a circuit can tolerate depends much on the physical layout, the parasitic inductances, and impedance levels, since they determine the phase errors in the loop. Thus, in general, the high-level stages should operate with lower feedback than the low-level stages.

The maximum amount of feedback the low-level driver can tolerate without noticeable deterioration in IMD is about 12 dB. This makes the total 16 dB, but from the data sheets we find that the combined gain variation for both devices from 2 to 30 MHz is around 29 dB. The difference, or 13 dB, should be handled by the gain-leveling networks.

The input impedance of the MRF476 is 7.55, -j0.65 ohms at 30 MHz resulting in the base-to-base impedance of 2 x $\sqrt{(7.55^2 + 0.65^2)}$ = 15.2 ohms. This, in series with networks R1, C1 and R4, C3 (2 x 4.4 ohms), gives 24 ohms, and would require a 2:1 impedance ratio transformer for a 50-ohm interface. However, due to the influence of strong negative feedback in this stage, a better overall matching is possible with 4:1 ratio. The input networks were designed in a manner similar to that described in Reference 8.

*Wallkill, N.Y. 12589

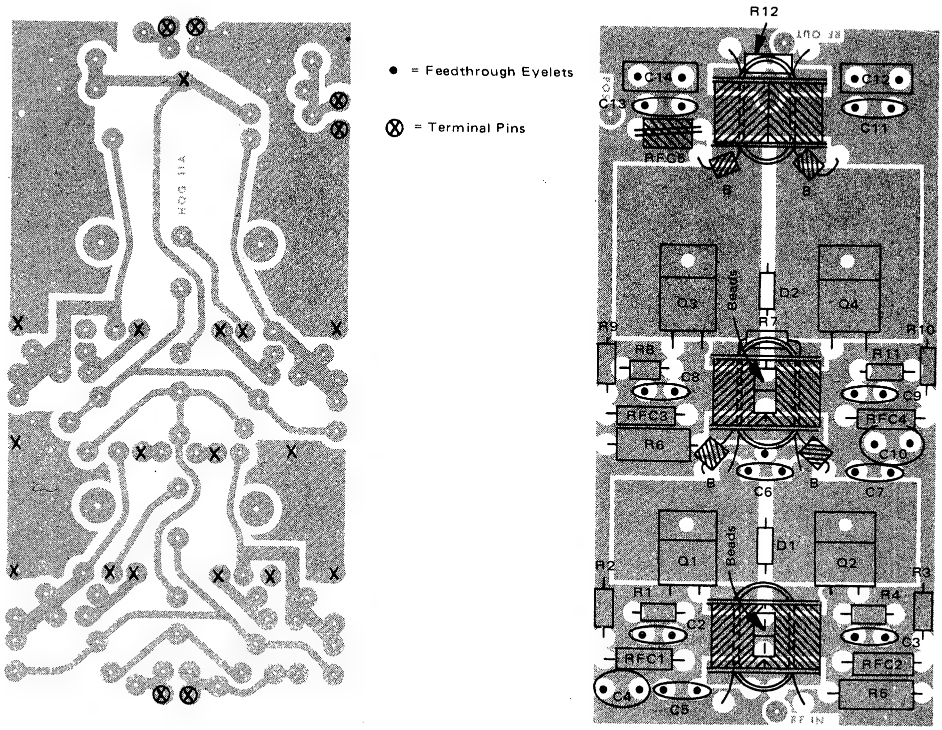



**FIGURE 5**
**Component Layout Diagram of Low-Cost 20 W Amplifier**

The leads of R7 and R12 form the one-turn feedback windings in T2 and T3. Ferrite beads in dc line can be seen located under T1 and T2.

## Measurements and Performance Data

At a power output of 20 W CW, all output harmonics were measured about 30 dB or more below the fundamental, except for the third harmonic which was only attenuated 17 dB to 18 dB at frequencies below 5 MHz. Typical numbers for the higher order distortion products ($d_9$ and $d_{11}$) are in the order of -60 dB above 7 MHz and -50 dB to -55 dB at the lower frequencies. These both can be substantially reduced by increasing the idle currents, but larger heat sinks would be necessary to accommodate the increased dissipation.

The efficiency shown in Figure 6 represents the overall figure for both stages. Currents through the bias networks, which are 82/(13.6 - 0.7) = 0.16 A each, are excluded. Modified values for R5 and R6 may have to be selected, depending on the forward voltage characteristics of D1 and D2.

Although this amplifier was designed to serve as a 1.6 to 30 MHz broadband driver, it is suitable for the citizens band use as well. With some modifications and design shortcuts, the optimization can be concentrated to one frequency.

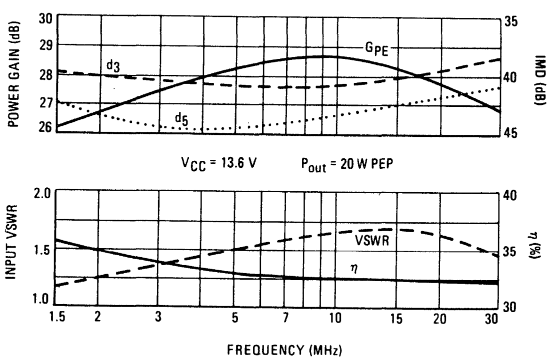



**FIGURE 6**

Intermodulation distortion and power gain versus frequency (upper curves).

Input VSWR and combined collector efficiency of both stages (lower curves).

## 20 W, 55 dB HIGH PERFORMANCE DRIVER
### 12-Volt Version

The second amplifier employs the MHW591 hybrid module to drive a pair of larger devices which can be operated Class A or AB, depending on the requirements. Transistors such as MRF449 and MRF455 are recommended for Class A and MRF433 for Class AB operation. A 24–28 volt version with MHW592 and a pair of MRF401s was also designed, and some of the test data will be presented. For Class A, the power parts should be replaced with MRF426s.*

These amplifiers are a good example of how a good gain flatness can be achieved across the four-octave band, with simple RC input networks and negative feedback, while maintaining a reasonable input VSWR.

The MHW591 is employed as a predriver in this unit. The MHW591 and its counterpart, MHW592, were developed for low-level SSB driver applications from 1.0 MHz to 250 MHz. The Class A operation results in a steady-state current drain of approximately 0.32 A, which does not vary with the signal level. At an output level of 600 mW PEP, the IMD is typically better than -40 dB, which can be considered sufficiently good for most purposes. Since the power gain is specified as 36.5 dB, the maximum drive level for the 600 mW output is 0.13 mW, or -9 dBM. For the final power output of 20 W, a power gain of 15.2 dB minimum is required at the highest operating frequency for the power transistors. A good, inexpensive device for this is the MRF433, which has a 20 dB minimum gain and -30 dB IMD specification at an output level of 12.5 W PEP. The push-pull configuration, due to inconsistent ground planes and broadbanding due to matching compromises usually results in 2 dB to 3 dB gain losses from figures measured in a test fixture. Assuming a transistor power gain of 18 dB, the total will be 54.5 dB, representing an input power of -11 dBM. Later measurements, however, indicated a gain of 56 dB (±0.5 dB) at the specified power output, making the input level around -13 dBM.

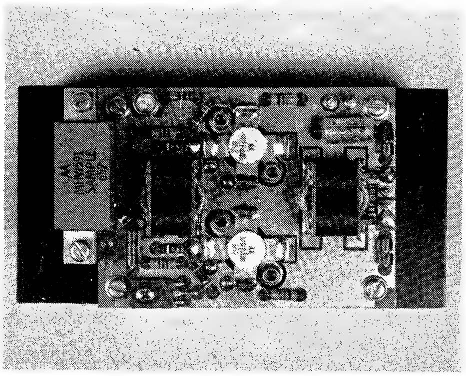


FIGURE 7

### Biasing and Feedback

The bias circuit employed with this amplifier is basically similar to the one described earlier, with the exception of having an emitter follower output. A second diode in series with the one normally seen with the clamping diode method compensates for the voltage drop in the base-emitter junction of the emitter follower, Q1 (Figure 8). The minimum current through D1 and D2 is $(I_C/h_{FE})$ (Q2 + Q3)/$h_{FE}$(Q1), and in this case (2.5/40)/40 = 1.5 mA. Typical $h_{FE}$ for the MRF433 is 40, and with the devices biased to 200 mA each, the standby base current is 10 mA. In operation the load current of Q1 then varies between 10 and 62 mA. A Case 77 transistor exhibiting low variations in base-emitter saturation voltage over this current range is MJE240. Base-emitter saturation voltage determines the bias source impedance, which should not exceed approximately 0.3 ohm, representing a 20 mV variation in voltage from idle to full drive conditions. If source impedance exceeds 0.3 ohms, a capacitor of 500–1000 μF should be connected from the emitter of Q1 to ground.

The peak dissipation of Q2 is under one watt, making it possible to mount the transistor directly to the circuit board without requiring any additional heat sinking.

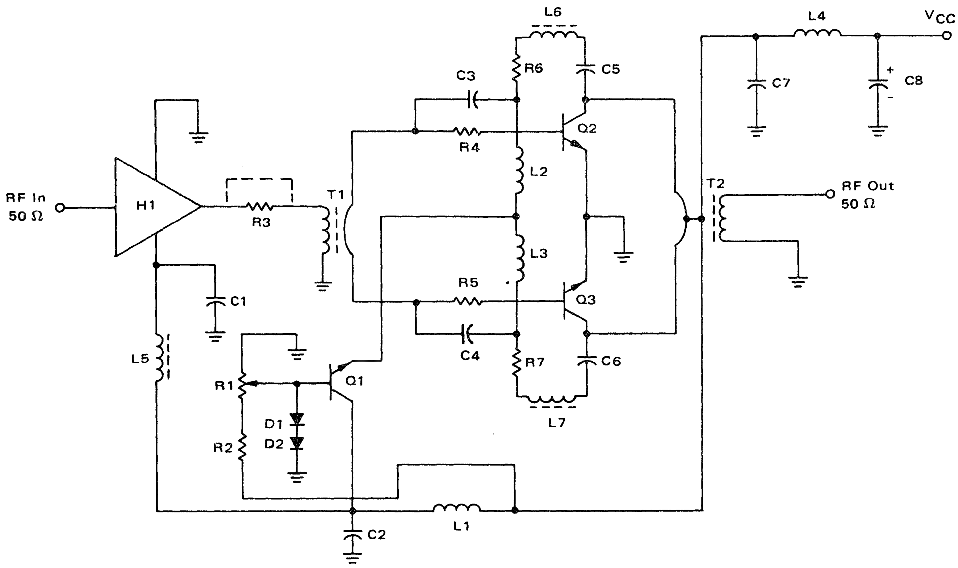
Diodes D1 and D2 are located on the lower side of the board, near Q2 and Q3 (Figure 9). The leads are formed to allow the diodes to come into contact with the transistor flanges. The thermal contact achieved in this manner is not the best possible, even when the gaps are filled with silicone compound, but the thermal time constant is lower than with most other methods. Both diodes are used for temperature tracking, although the voltage drop of only one is required to compensate for the $V_{BE}$ forward drop of Q1. The advantages of this circuit are simplicity, low standby current drain, and ease of adjustment with a small trimpot.

The voltages for the negative feedback are derived separately from the collectors of Q2 and Q3 through L6, R6 and L7, R7. Capacitors C5 and C6 are used for dc isolation. Because of the high RF voltage levels on the collectors, this method is only feasible in low- and medium-power amplifiers. At higher power levels, the power-handling requirements for the series resistors (Figure 8), which must be noninductive, become impractical. A feedback voltage source with lower impedance must be provided in such cases.[8]

The MRF433 has a higher figure of merit (emitter periphery/base area) than the MRF475, for example. This results in smaller differences in power gain per given bandwidth, since the device is operating farther away from the 6 dB/octave slope.[9] Disregarding the package inductances, which affect the Q, the higher figure of merit makes such devices more suitable for broadband operation. The 2 MHz to 30 MHz $\Delta G_{PE}$ of the MRF433 is 8 dB, which is divided equally between the negative feedback and the leveling networks C3, R4 and C4, R5. The 2 MHz and 30 MHz impedance values are 9.1, -j3.5 and 2.5, -j2.2 ohms, respectively, although the 2 MHz values are not given in the data sheet.

At 30 MHz we can first determine what type of transformer is needed for the 50-ohm input interface. The effective transformer load impedance is $2\sqrt{(2.5^2 + 2.2^2)}$ + 2(2.4) ohms (leveling networks) = 11.5 ohms, which indicates that a 4:1 impedance ratio is the closest possible (see Figures 3B, 4A, and 8). These values are accurate for practical purposes, but they are not exact, since part of the capacitive reactance in C3 and C4 will be cancelled, depending on the transformer characteristics.

*To be introduced.




L1, L4, L5 — Ferrite Beads (Fair-Rite Products Corp. #2643000101 or Ferroxcube #56 590 65/3B or equivalent)
L2, L3 — 10 μH Molded Choke
L6, L7 — 0.1 μH Molded Choke
Q1 — MJE240
Q2, Q3 — MRF433
H1 — MHW591
T1, T2 — 4:1 and 1:4 Impedance Transformers, respectively. (See discussion on transformers.) Ferrite Beads are Fair-Rite #2643006301 or equivalent)

R1 — 1 Ohm Trimpot
R2 — 1 k Ohm, 1/4 W
R3 — Optional
R4, R5 — 5. 6 Ohms, 1/4 W
R6, R7 — 47 Ohms, 1/4 W
C1, C2, C5, C6, C7 — 0.01 μF Chip
C3, C4 — 1800 pF Chip
C8 — 10 μF/35 V Electrolytic

**FIGURE 8**

The output matching is done with a transformer similar to that described in the first part of this paper (Figures 4B, 4C). This transformer employs a multi-turn primary, which can be provided with a center tap for the collector dc feed. In addition to a higher primary inductance, more effective coupling between the two transformer halves is obtained, which is important regarding the even-order harmonic suppression.

**28-Volt Version**

A 28-V version of this unit has also been designed with the MHW592 and a pair of MRF401s. The only major change required is the output transformer, which should have a 1:1 impedance ratio in this case. The transformer consists of six turns of RG-196 coaxial cable wound on an Indiana General F-627-8-Q1 toroid. Each end of the braid is connected to the collectors, and the inner conductor forms the secondary. A connection is made in the center of the braid (three turns from each end) to form the center tap and dc feed.

The MRF433 and MRF401 have almost similar input characteristics, and no changes are necessary in the input circuit, except for the series feedback resistors, which should be 68–82 ohms and 1 W.

In designing the gain-leveling networks, another approach can be taken, which does not involve the computer program described in Reference 8. Although the input VSWR is not optimized, it has proved to give satisfactory results.

The amount of negative feedback is difficult to determine, as it depends on the device type and size and the physical circuit layout. The operating voltage has a minimal effect on the transistor input characteristics, which are more determined by the electrical size of the die. High-power transistors have lower input impedances and higher capacitances, and phase errors are more likely to occur due to circuit inductances.

Since the input capacitance is an indication of electrical size of the device, we can take the paralleled value ($X_p$) at 2 MHz, which is $X_S + (R_S{}^2/X_S)$ and for MRF433 $3.5 + (9.1^2/3.5) = 27$ ohms. The $X_p$ of the largest devices available today is around 10 ohms at 30 MHz, and experience has shown that the maximum feedback should be limited to about 5 dB in such case. Using these figures

as constants, and assuming the $G_{PE}$ is at least 10 dB, we can estimate the amount of feedback as: $5/(10^2/27) + 5 = 6.35$ dB, although only 4 dB was necessary in this design due to the low $\Delta G_{PE}$ of the devices.

The series base resistors (R4 and R5) can be calculated for 4 dB loss as follows:

$$\frac{[(V_{in} \times \Delta 4dB) - V_{in}]}{I_{in}} = \frac{[(0.79 \times 1.58) - 0.79]}{0.04}$$

$$= 11.45 \text{ ohms, or}$$

$$11.45/2 = 5.72 \text{ ohms each.}$$

$Z_{in}(2\ \text{MHz}) = \sqrt{(9.1^2 + 3.5^2)} = 9.75$ ohms, in Class AB push-pull 19.5 ohms.

$P_{in} = 20\ \text{W} - 28\ \text{dB} = 20/630 = 0.032\ \text{W}$

$V_{RMS}$ (base to base) $= \sqrt{(0.032 \times 19.5)} = 0.79$ V

$I_{in} = V_{in}/R_{in} = 0.79/19.5 = 0.04$ A

$\Delta V4\ \text{dB} = \sqrt{[\text{Log}^{-1}(4/10)]} = 1.58$ V

The parallel capacitors (C3 and C4) should be selected to resonate with R (5.7 ohms) somewhere in the mid-band. At 15 MHz, out of the standard values, 1800 pF appears to be the closest, having a negligible reactance at 2 MHz, and 2.8 ohms at 30 MHz, where most of the capacitive reactance is cancelled by the transformer winding inductance.

**Measurements and Performance Data**

The output harmonic contents of this amplifier are substantially lower than normally seen in a Class AB system operating at this power level and having a 4.5-octave bandwidth. All harmonics except the third are attenuated more than 30 dB across the band. Between 20 and 30 MHz, -40 to -55 dB is typical. The third harmonic

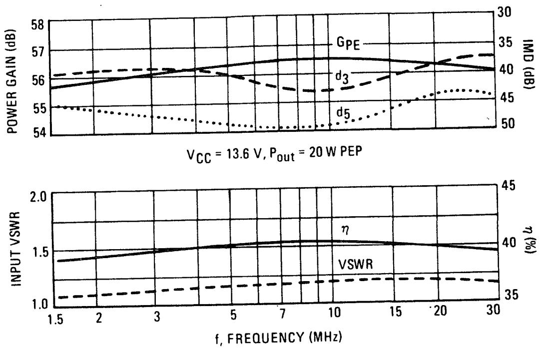



**FIGURE 10**

Intermodulation Distortion and Power Gain versus Frequency (Upper Curves). Input VSWR and Collector Efficiency (excluding MHW591) (Lower Curves).

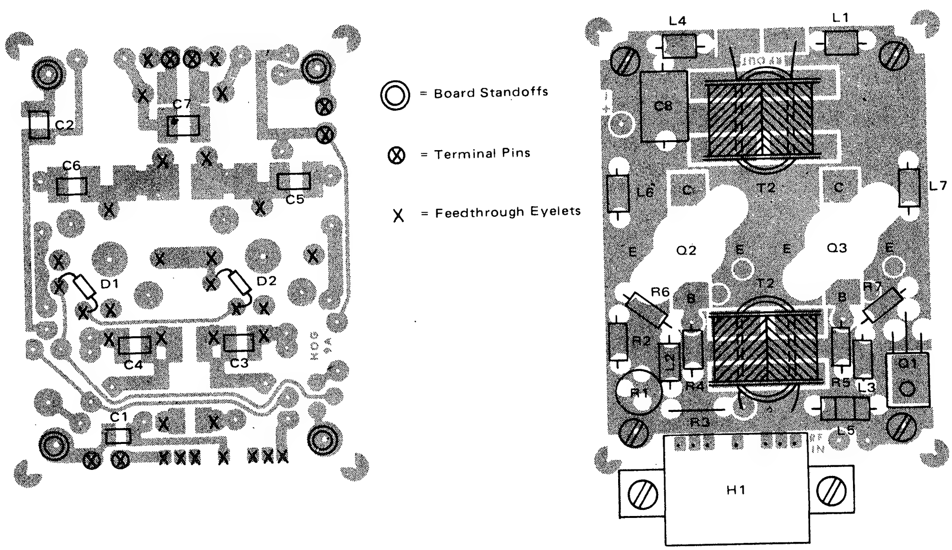



**FIGURE 9**
**Component Layout Diagram of**
**20 W, 55 dB High-Performance Driver**

The leads of D1 and D2 are bent to allow the diodes to contact the transistor mounting flanges.

Note that the mounting pad of Q1 must be connected to the lower side of the board through an eyelet or a plated through-hole.

has its highest amplitude (-20 to -22 dB), as can be expected, below 20 MHz. The measurements were done at an output level of 20 W CW and with 200 mA collector idle current per device. Increasing it to 400 mA improves these numbers by 3–4 dB, and also reduces the amplitudes of $d_5$, $d_7$, $d_9$, and $d_{11}$ by an average of 10 dB, but at the cost of 2-3 dB higher $d_3$.

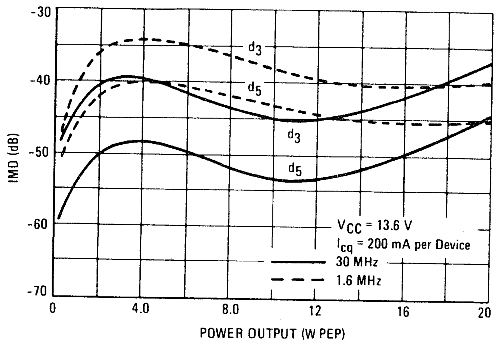



**FIGURE 11 — IMD versus Power Output**

## CONCLUSION

The stability of both designs (excluding the 28 V unit) was tested into reactive loads using a setup described in Reference 8. Both were found to be stable into 5:1 load mismatch up to 7 MHz, 10:1 up to 30 MHz, except the latter design did not exhibit breakups even at 30:1 in the 20-30 MHz range. If the test is performed under two-tone conditions, where the power output varies from zero to maximum at the rate of the frequency difference, it is easy to see at once if instabilities occur at any power level.

The two-tone source employed in all tests consists of a pair of crystal oscillators, separated by 1 kHz, at each test frequency. The IMD ($d_3$) is typically -60 dB and the harmonics -70 dB when one oscillator is disconnected for CW measurements.

HP435 power meters were used with Anzac CH-130-4 and CD-920-4 directional couplers and appropriate attenuators. Other instruments included HP141T analyzer system and Tektronix 7704A oscilloscope-spectrum analyzer combination.

## REFERENCES


1. "Linearized Class B Transistor Amplifiers," IEEE Journal of Solid State Circuits, Vol. SC-11, No. 2, April, 1976.

2. Pappenfus, Bruene and Schoenike, "Single Sideband Principles and Circuits," McGraw-Hill.

3. Reference Data for Radio Engineers, ITT, Howard & Sams Co., Inc.

4. H. Grandberg, "Broadband Transformers and Power Combining Techniques for RF," AN-749, Motorola Semiconductor Products Inc.

5. H. Grandberg, "Measuring the Intermodulation Distortion of Linear Amplifiers," EB-38, Motorola Semiconductor Products Inc.

6. K. Simons, Technical Handbook for CATV Systems, Third Edition, Jerrold Electronics Corp.

7. Data Sheets, Motorola MRF475, MRF476, MRF433, and MHW591

8. H. Grandberg, "Two-Stage 1 KW Solid-State Linear Amplifier," AN-758, Motorola Semiconductor Products Inc.

9. Phillips, "Transistor Engineering," McGraw-Hill.

# A Complementary Symmetry Amplifier for 2—30-MHz SSB Driver Applications

*Prepared by:*
**Helge Granberg**

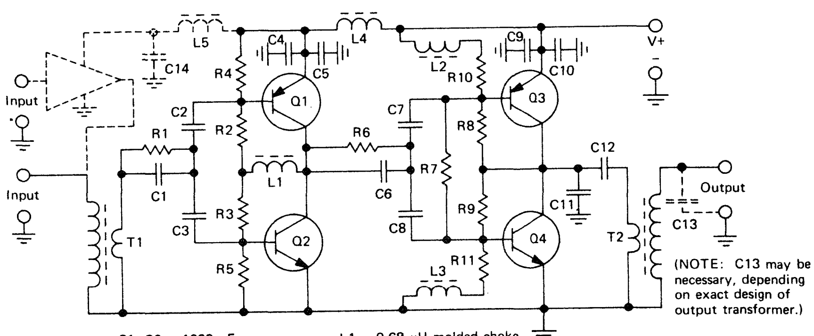
Where harmonic rejection and low intermodulation distortion are important, try this new two-stage complementary symmetry amplifier. It combines push-pull design, single-ended impedance matching with high gain from the MRF432/433 to provide up to 25 watts PEP for driver applications. Power gain is typically 35 dB, depending on the supply (22 to 30 volts).

The circuit board layout has a provision for adding a hybrid amplifier to raise the total power gain to 45 to 50 dB so that the amplifier can be driven directly from a balanced modulator. Motorola's MHW570-MHW572 line extender and trunk amplifiers are suitable if gain compensation is modified for rolloff below 5 MHz.

**Biasing Techniques**

The first stage (Q1 and Q2 in figure 1) is biased to class A for improved even order harmonic rejection and lower IMD. Quiescent collector current (Icq) is set to 700 mA by adjusting the values of R2, R3, R4 and R5. The second stage (Q3 and Q4) is biased in class AB with a quiescent collector current of 70 to 80 mA by R7, R8, R9, R10 and R11. Gain compensation is performed with R1, C1 and R6, C6. Both stages are provided with negative collector-to-base feedback and the reactance of L1 is employed to produce a slightly increasing gain slope with frequency (0.8 dB/octave). The total gain curve is shown in figure 2.

FIGURE 1. Complementary Symmetry Amplifier Schematic




C1, C6 – 1000 pF
C2, C3, C7, C8 – 0.1 μF
C4, C9, C14 – 0.15 μF
C5, C10, C12 – 0.68 μF
C11 – 2000 pF
C13 – 100 pF (Typ.)

R1, R4, R5 – 22 ohms/1/4 W
R2, R3 – 330 ohms/1/2 W
R6 – 15 ohms/1/4 W
R8, R9 – 220 ohms/1 W
R10, R11 – 6.8 ohms/1/2 W
R7 – 560–680 ohms/2 W

L1 – 0.68 μH molded choke
L2, L3 – 6.8 μH molded choke
L4 – 4 ferrite beads, Ferroxcube 56 590 65/3B

Q1, Q3 – MRF432
Q2, Q4 – MRF433

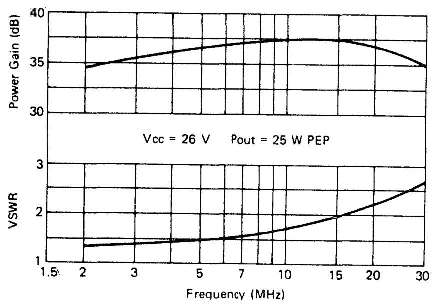
T1, T2 – See text

All capacitors are ceramic chips, Union Carbide type 1225 or 1813 or Varadyne size 18 or 14 or equivalent.
All resistors are carbon composite.

### Impedance Matching

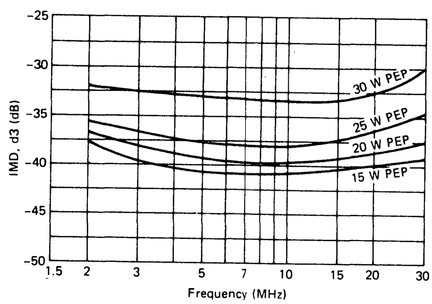
Midband input impedance of the first stage is approximately 5 ohms. The increasing feedback at low frequencies greatly reduces the impedance variations within the 2- to 30-MHz frequency band. When the R1C1 network is taken into account, the best overall match will be obtained with a 5:1 input transformer. However, for practical purposes, one with a 4:1 ratio may be substituted. This will result in a constant input VSWR lower than a 1.2:1 when the output is terminated in a 15-ohm resistive load, which will not comply with the output impedance formulas presented for class AB and B amplifiers in reference 1.

FIGURE 2. Power Gain and VSWR versus Frequency




Output impedance for low-power class A complementary amplifiers can be calculated as $\frac{(1/2\ Vce)^2}{Icq \times Vce}$ or simply $\frac{1/2\ Vce}{Icq}$. If a slightly larger device than necessary for class A is used, its load impedance can be varied by adjusting the operating point and, in this design, eliminates the need for an interstage matching transformer. Class AB operation of the second stage results in an input impedance of around 7 ohms at midband and can be measured in this single-ended, narrow-band circuit.

FIGURE 3. IMD versus Frequency




Assuming a 24-V supply, the output impedance of the first stage is $\frac{11.0}{0.7}$ = 15.7 ohms, when Vce (sat) is 1.0 V. The effective midband load impedance, taking R6 and C6 into account, is 13 ohms.

Because the higher-level, second stage is biased with a simple resistor network, it requires a fairly low bias source impedance. Since R10 and R11 are each of low value, inductors L2 and L3 provide a higher RF impedance for the transistor bases and with proper values, can also be a part of the gain compensation network.

FIGURE 4. Linear Output Power versus Supply Voltage

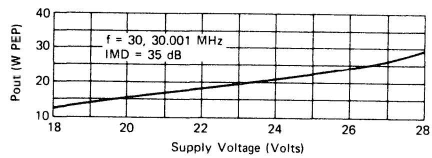
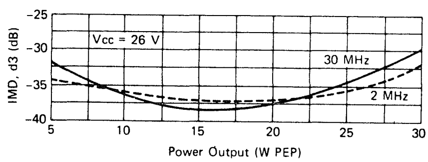



FIGURE 5. IMD versus Power Output



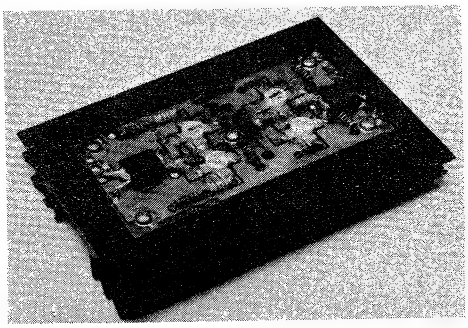

### Wideband Transformers

The load impedance of the second stage, according to the formula $\frac{Vcc^2}{2\ Pout}$ is $\frac{128}{40}$ = 3.2 ohms. While an impedance ratio of 15.6:1 would be optimum for a 50-ohm interface, for practical reasons a standard 16:1 impedance ratio transformer was chosen for this design. T1 and T2 are of same type, and both employ Stackpole dual balun ferrite cores No. 57-1845-24B ($u_r$ = 2400). Each of the dual cores can be replaced by two separate ferrite sleeves with similar magnetic characterisitcs.

In T1 and T2, the low-impedance windings consist of one turn of copper braid. The primary of T1 consists of two turns of AWG No. 22 Teflon®-insulated stranded wire. Four turns of similar wire are used for the secondary of T2. The physical construction of this type of transformer is described in Motorola EB-27.

The measured performance of the complementary symmetry amplifier shown in the photo is provided in figures 3, 4 and 5 and table 1. As a construction aid, top and bottom phantom views identify component locations. And the exact size reproductions of the PCB sides can be used as templates.

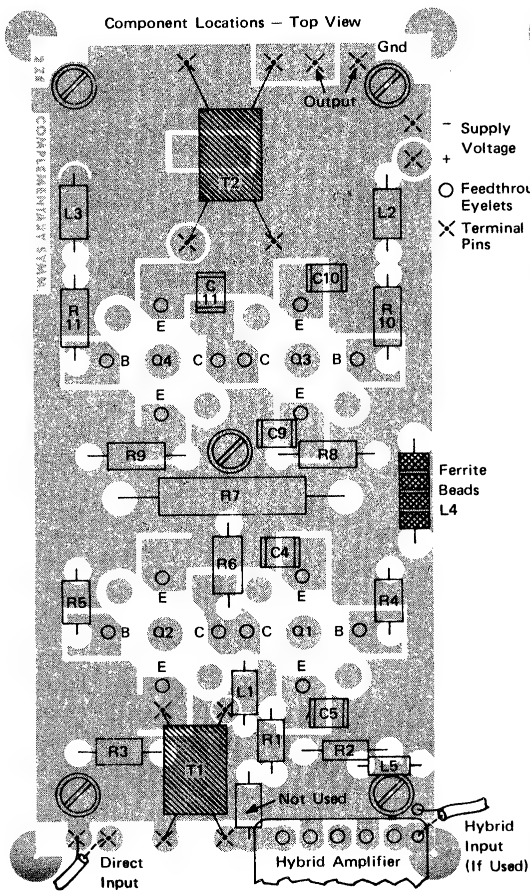
® Registered trademark of DuPont.

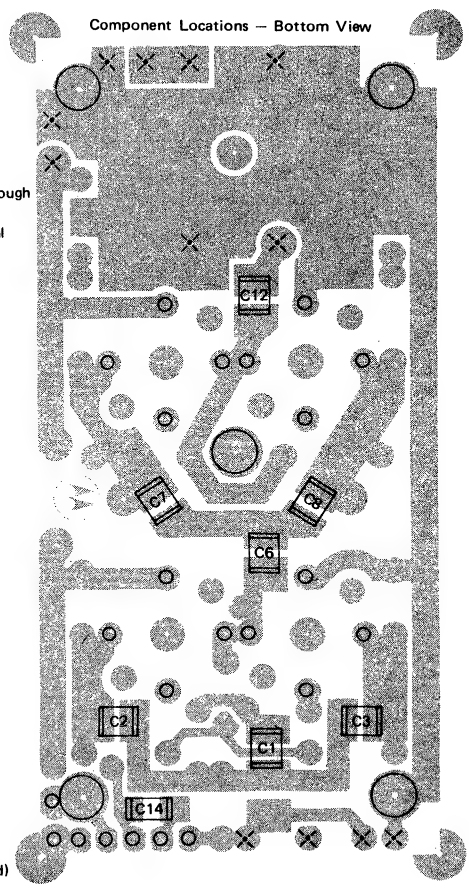


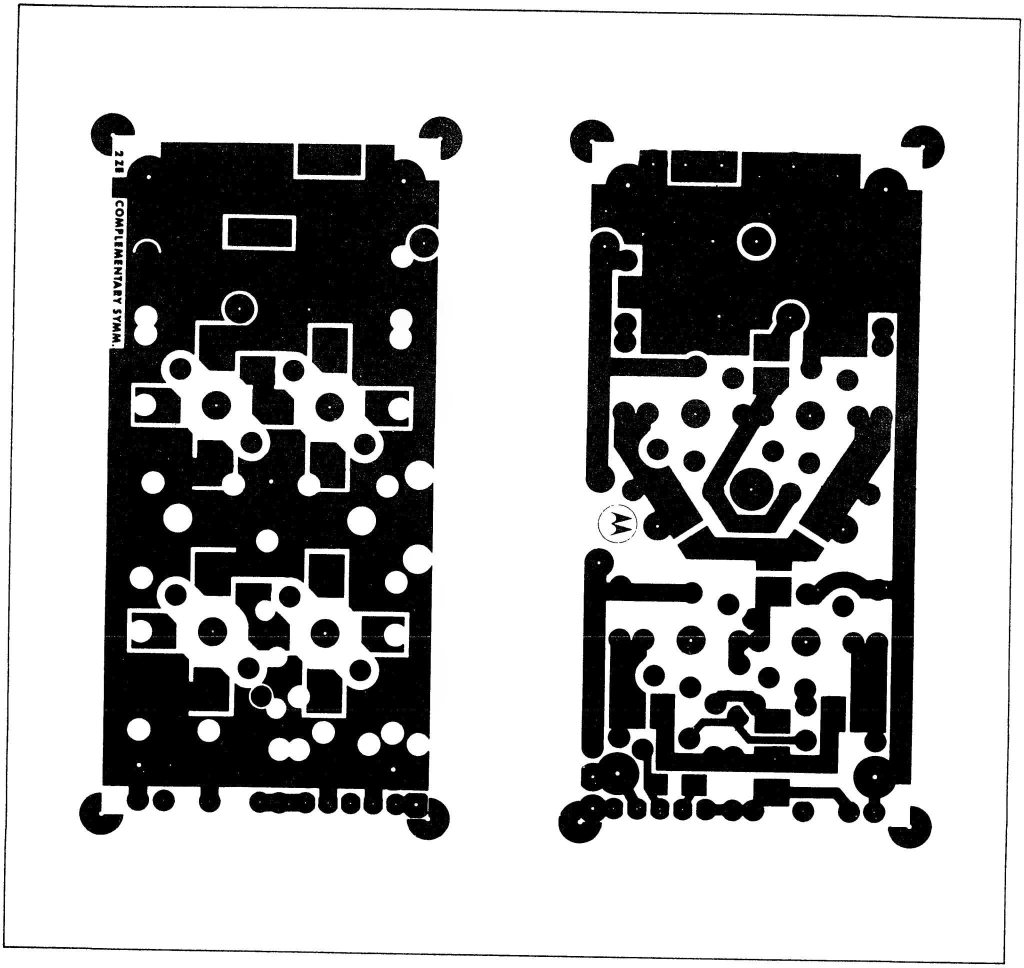
| Table 1. Output Harmonic Contents of Complementary Symmetry Amplifier | | | | | |
|---|---|---|---|---|---|
| Harmonic | → | (dB) | | | |
| | | 2nd | 3rd | 4th | 5th |
| Frequency (MHz) | 2.0 | -33 | -35 | -45 | -35 |
| | 4.0 | -33 | -36 | -39 | -35 |
| | 7.5 | -35 | -41 | -48 | -38 |
| | 15 | -33 | -24 | -45 | -55 |
| | 20 | -30 | -26 | -55 | -60 |
| | 30 | -30 | -52 | -50 | -60 |
| Data taken at power output of 20 W CW | | | | | |

**References:**

Granberg, H., Motorola Engineering Bulletin EB-27.






MOTOROLA Semiconductor Products Inc.

# BROADBAND TRANSFORMERS AND POWER COMBINING TECHNIQUES FOR RF

Prepared by:
**Helge O. Granberg**

## INTRODUCTION

The following discussion focuses on broadband transformers for RF power applications with practical examples of various types given with performance data. Detailed design formula are available in the Reference section. Power combining techniques useful in designing high power amplifiers are discussed in detail.

## BROADBAND TRANSFORMERS

The input and output transformers are among the most critical components in the design of a multi-octave amplifier. The total performance of the amplifier (linearity, efficiency, VSWR, gain flatness) will depend on their quality. Transformers with high impedance ratios and for low impedances are more difficult to design in general. In the transmission line transformers very low line impedances are required, which makes them impractical for higher than 16:1 impedance ratios in a 50-Ohm system. Other type transformers require tight coupling coefficients between the primary and secondary, or excessive leakage inductances will reduce the effective bandwidth. Twisted line transformers (Figure 1C, D, F, G) are described in References 1, 2, and 4. Experiments have shown that the dielectric losses in certain types of magnet wire, employed for the twisted lines, can limit the power handling capability of such transformers. This appears as heat generated within the transformer at higher frequencies, although part of this may be caused by the losses in the magnetic core employed to improve the low frequency response. At low frequencies, magnetic coupling between the primary and secondary is predominant. At higher frequencies the leakage inductance increases and the permeability of the magnetic material decreases, limiting the bandwidth unless tight capacitive coupling is provided. In a transmission line transformer this coupling can be clearly defined in the form of a line impedance.

The required minimum inductance on the low impedance side is:

$$L = \frac{4\,R}{2\pi f} \quad \text{where} \quad \begin{aligned} L &= \text{Inductance in } \mu\text{H} \\ R &= \text{Impedance in Ohms} \\ f &= \text{Frequency in MHz} \end{aligned}$$

This applies to all transformers described here.

Some transformers, which exhibit good broad band performance and are easy to duplicate are shown in Figure 1.

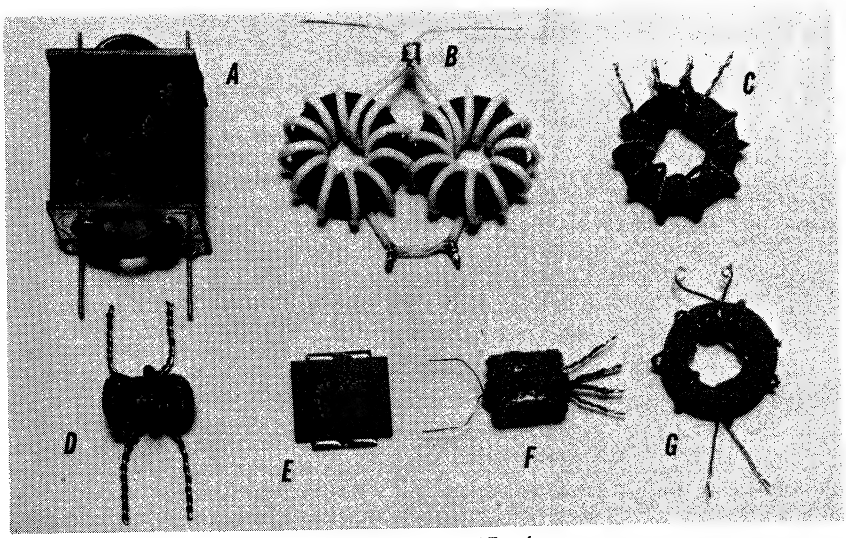



FIGURE 1 – HF Broadband Transformers

Transformers E and F are intended for input applications, although A in a smaller physical form is also suitable. In E, the windings are photo etched on double sided copper-Kapton* (or copper-fiberglass) laminate. The dielectric thickness is 3 mils, and the winding area is 0.25 $in^2$.

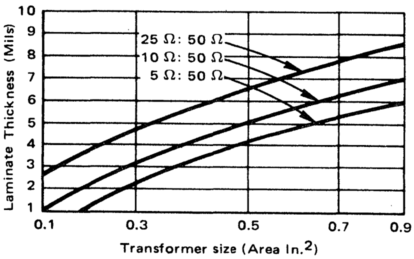



**FIGURE 2 – Laminate Thickness versus Winding Area**

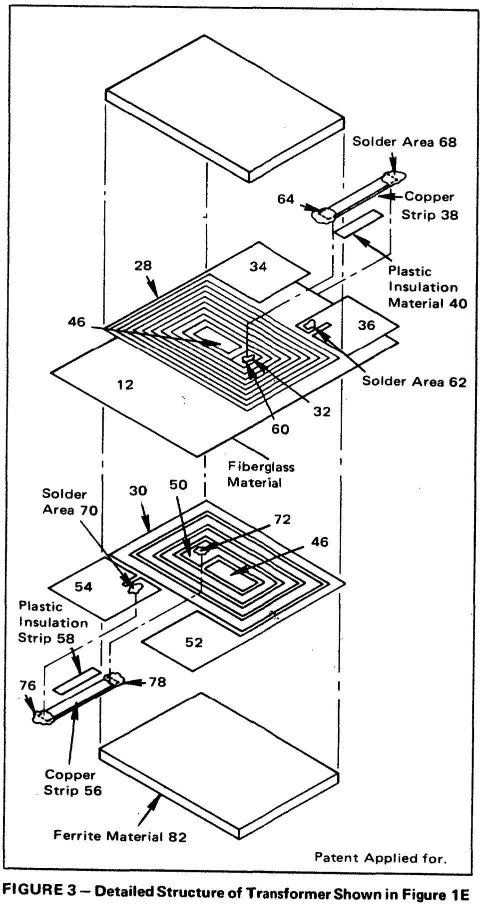


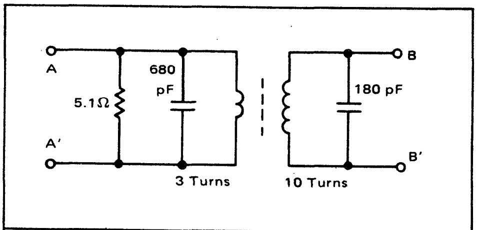

**FIGURE 3 – Detailed Structure of Transformer Shown in Figure 1E**

*Trademark of E. I. DuPont, De Nemours and Co., Inc.

Ferrite plates ($\mu_r$ = 2000 to 3000) are cemented on each side to improve the low frequency response. This type transformer in the size shown, can handle power levels to 10 W. Figure 2 shows curves for laminate thickness versus winding area for various impedance ratios.

Impedance ratios of this transformer are not limited to integers as 1:1, 4:1 –– N:L, and the dc isolated primary and secondary have an advantage in certain circuit configurations. This design will find its applications in high volume production or where the small physical size is of main concern. Table 1 shows the winding configuration and measured data of the transformer shown in Figure 3.

**TABLE 1 – Impedance at Terminals BB′**
**Transformer Terminated as Shown**




| f (MHz) | $R_p$ (Ohms) | $X_p$ (Ohms) |
|---|---|---|
| 1.0 | 50.7 | +j 81 |
| 2.0 | 53.0 | +j 185 |
| 4.0 | 53.1 | +j 1518 |
| 8.0 | 53.5 | -j 214 |
| 16.0 | 50.5 | -j 79 |
| 32.0 | 52.9 | -j 30 |

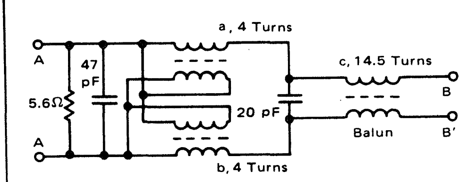
In the transformer shown in Figure 1F and Table 2, a regular antenna balun core is employed (Indiana General F684-1 or equivalent). Lines A and B each consist of two twisted pairs of AWG #30 enameled wire. The line impedances are measured as 32 Ohms, which is sufficiently close to the optimum 25 Ohms calculated for 4:1 impedance ratio. ($Z_o = \sqrt{R_{in}\,R_L}$).

Windings a and b are wound one on top of the other, around the center section of the balun core. Line c should have an optimum $Z_o$ of 50 Ohms. It consists of one pair of AWG #32 twisted enameled wire with the $Z_o$ measured as 62 Ohms. The balun core has two magnetically isolated toroids on which c is wound, divided equally between each. The industance of c should approach the combined inductance of Lines a and b (Reference 4, 6).

The reactance in the 50 Ohm port (BB′) should measure a minimum of + j 200. To achieve this for a 4:1 transformer, a and b should each have three turns, and for a 9:1 transformer, four turns. When the windings are connected as a 9:1 configuration, the optimum $Z_o$ is 16.6 Ohms, and a larger amount of high frequency compensation will be necessary. Lower impedance lines can be realized with heavier wires or by twisting more than two pairs together. (e.g., four pairs of AWG #36 enameled wire

would result in the $Z_O$ of approximately 18 Ohms.) Detailed information on the manufacture of twisted wire transmission lines can be found in References 2, 4, and 8. 9.

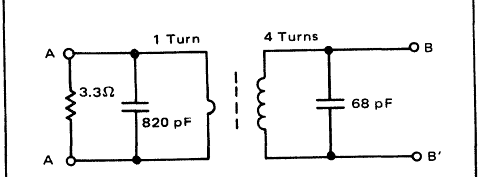
**TABLE 2 — Impedance at Terminals BB' Transformer Terminated as Shown**




| f (MHz) | $R_p$ (Ohms) | $X_p$ (Ohms) |
|---|---|---|
| 1.0 | 53.0 | +j 185 |
| 2.0 | 52.6 | +j 330 |
| 4.0 | 52.9 | +j 430 |
| 8.0 | 53.1 | +j 600 |
| 16.0 | 53.2 | +j 750 |
| 32.0 | 53.5 | +j 3060 |

Figure 1A shows one of the most practical designs for higher impedance ratios (16 and up). The low impedance winding always consists of one turn, which limits the available ratios to integers 1, 4, 9 —— N. Data taken of this type of a 16:1 transformer is shown in Table 3, while Figure 4 illustrates the physical construction. Two tubes, 1.4" long and 1/4" in diameter – copper or brass – form the primary winding. The tubes are electrically shorted on one end by a piece of copper-clad laminate with holes for the tubes and the tube ends are soldered to the copper foil. The hole spacing should be larger than the outside diameter of the ferrite sleeves.

**TABLE 3 — Impedance at Terminals BB' Transformer Terminated as Shown**




| f (MHz) | $R_p$ (Ohms) | $X_p$ (Ohms) |
|---|---|---|
| 1.0 | 54.0 | +j 1030 |
| 2.0 | 54.0 | +j 3090 |
| 4.0 | 54.0 | +j 5800 |
| 8.0 | 53.9 | -j 300 |
| 16.0 | 53.1 | -j 760 |
| 32.0 | 53.2 | -j 600 |

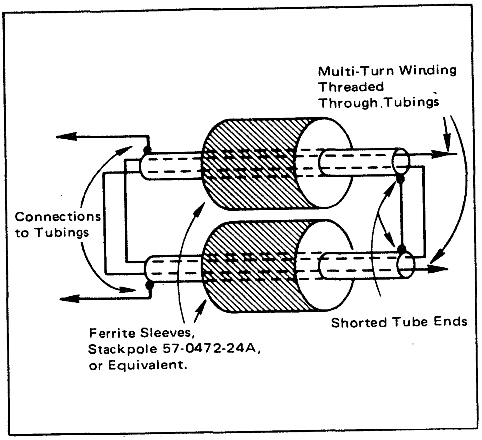



**FIGURE 4 — Physical Construction of a 16:1 Transformer (Actual Number of Turns Not Shown)**

A similar piece of laminate is soldered to the opposite ends of the tubes, and the copper foil is divided into two sections, thus isolating the ends where the primary connections are made. The secondary winding is formed by threading wire with good RF insulating properties through the tubes for the required number of turns.

Although the measurements indicate negligible differences in performance for various wire sizes and types (stranded or solid), the largest possible diameter should be chosen for lower resistive losses. The initial permeability of the ferrite sleeves is determined by the minimum inductance required for the lowest frequency of operation according to the previous formula. Typical $\mu_r$'s can vary from 800 to 3000 depending upon the cross sectional area and lowest operating frequency. Instead of the ferrite sleeves, a number of toroids which may be more readily available, can be stacked.

The coupling coefficient between the primary and secondary is almost a logarithmic function of the tube diameter and length. This factor becomes more important with very high impedance ratios such as 36:1 and up, where higher coupling coefficients are required. The losses in the ferrite are determined by the frequency, permeability and flux density. The approximate power handling capability can be calculated as in Reference 4 and 6, but the ferrite loss factor should be taken into consideration. The $\mu_r$ in all magnetic materials is inversely proportional to the frequency, although very few manufacturers give this data.

Two other variations of this transformer are shown in Figure 5. The smaller version is suitable for input matching, and can handle power levels to 20 W. It employs a stackpole dual balun ferrite core 57-1845-24B. The low impedance winding is made of 1/8" copper braid. The portions of braid going through the ferrite are rounded, and openings are made in the ends with a pointed tool. The high impedance winding is threaded through the rounded portions of the braid, which was uncovered in each end of the ferrite core. (See Figures 4 and 5.)

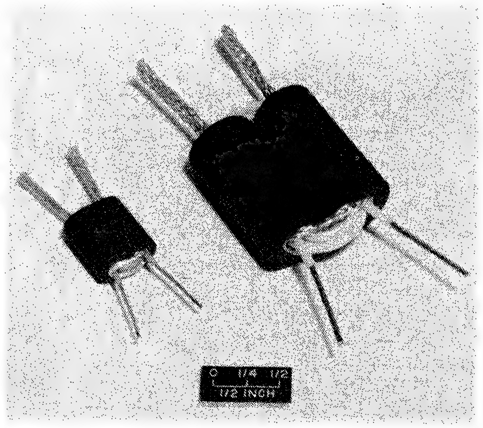



**FIGURE 5 – Variations of Transformers in Figure 1A**

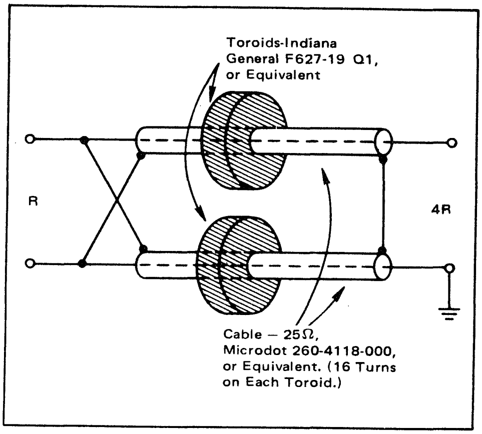



**FIGURE 6 – Transformer Construction (Figure 1B)**

The construction technique of the larger version transformer is similar, except two separate ferrite sleeves are employed. They can be cemented together for easier handling. This transformer is intended for output applications, with a power handling capability of 200-250 W employing Stackpole 57-0472-27A ferrites. For more detail, see Reference 7.

The transformer shown in Figure 1B is superior in bandwidth and power handling capability. Table 4 shows data taken on a 4:1 transformer of this type. The transmission lines (a and b) are made of 25-Ohm miniature co-axial cable, Microdot 260-4118-000 or equivalent. Two 50 Ohm cables can also be connected in parallel.

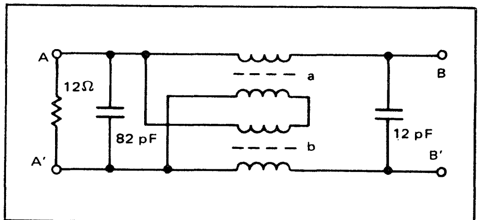
The balun, normally required to provide the balanced to unbalanced function is not necessary when the two transmission lines are wound on separate magnetic cores, and the physical length of the lines is sufficient to provide the necessary isolation between AA′ and BB′. The minimum line length required at 2.0 MHz employing Indiana General F627-19-Q1 or equivalent ferrite toroids is 4.2 inches, and the maximum permissible length at 30 MHz would be approximately 20 inches, according to formulas 9 and 10 presented in Reference 2. The 4.2 inches would amount to four turns on the toroid, and measures 1.0 $\mu$H. This complies with the results obtained with the formula given earlier for minimum inductance calculations.

Increasing the minimum required line length by a factor of 4 will provide the isolation, and the total length is still within the calculated limits. The power loss in this PTFE insulated co-axial cable is 0.03 dB/ft at 30 MHz in contrast to 0.12 dB/ft for a twisted wire line. The total line loss in the transformer will be about 0.1 dB

The number of turns on the toroids has been increased beyond the point where the flux density of the magnetic core is the power limiting factor. The combined line and core losses limit the power handling capability to approximately 300 W, which can be slightly increased by employing lower loss magnetic material.

Note the connection arrangement (Figure 6), where the braid of the cable forms the high current path of the primary.

**TABLE 4 – Impedance at Terminals BB′ Transformer Terminated as Shown**




| f (MHz) | $R_p$ (Ohms) | $X_p$ (Ohms) |
|---|---|---|
| 1.0 | 48.3 | +j 460 |
| 2.0 | 48.1 | +j 680 |
| 4.0 | 48.0 | +j 920 |
| 8.0 | 48.0 | +j 1300 |
| 16.0 | 48.1 | +j 900 |
| 32.0 | 48.1 | +j 690 |

## HIGH-FREQUENCY POWER COMBINING TECHNIQUES EMPLOYING HYBRID COUPLERS

The zero degree hybrids described here are intended for adding the powers of a multiple of solid-state amplifiers, or to combine the outputs of groups of amplifiers, usually referred to as modules. With this technique, powers to the kW level at the high-frequency bands can be realized.

When reversed, the hybrids can be used for splitting signals into two or more equal phase and amplitude ports. In addition, they provide the necessary isolation between the sources. The purpose of the isolation is to keep the system operative, even at a reduced power level during a possible failure in one amplifier or module. The isolation is especially important in output combining of linear

amplifiers, where a constant load impedance must be maintained. Sometimes the inputs can be simply paralleled, and a partial system failure would not have catastrophic effects, but will merely result in increased input VSWR.

For very high frequencies and narrow bandwidths, the hybrid couplers may consist of only lengths of transmission line, such as co-axial cable. The physical lengths of the lines should be negligible compared to the highest operating frequency to minimize the resistive losses, and to avoid possible resonances. To increase the bandwidth and improve the isolation characteristics of the line, it is necessary to increase the impedance for non-transmission line currents (parallel currents) without effecting its physical length. This can be done by loading the line with magnetic material. Ideally, this material should have a linear BH curve, high permeability and low losses over a wide frequency range. For high-frequency applications, some ferrites offer satisfactory characteristics, making bandwidths of four or more octaves possible.

Depending upon the balance and phase differences between the sources, the currents should be mostly cancelled in the balun lines. In a balanced condition, very little power is dissipated in the ferrite cores, and most occurring losses will be resistive. Thus, a straight piece of transmission line loaded with a high permeability ferrite sleeve, will give better results than a multiturn toroid arrangement with its inherent higher distributed winding capacitance.

It is customary to design the individual amplifiers for 50 Ohm input and output impedances for testing purposes and standardization. 50-and 25-Ohm co-axial cable can then be employed for the transmission lines. Twisted wire lines should not be used at power levels higher than 100 Watts average, due to their higher dielectric losses.

Variations of the basic hybrid are shown in Figure 7A and B where both are suitable for power dividing or combining.

The balancing resistors are necessary to maintain a low VSWR in case one of the 50-Ohm points reaches a high impedance as a result of a transistor failure. As an input power splitter, neither 50-Ohm port will ever be subjected to a short due to the base compensation networks, should a base-emitter junction short occur. An open junction will result in half of the input power being dissipated by the balancing resistor, the other half still being delivered to the amplifier in operation. The operation is reversed when the hybrid is used as an output combiner. A transistor failure will practically always cause an increase in the amplifier output impedance. Compared to the 50-Ohm load impedance it can be regarded as an open circuit. When only one amplifier is operative, half of its output power will be dissipated by R, the other half being delivered to the load. The remaining active source will still see the correct load impedance, which is a basic requirement in combining linear amplifiers. The resistors (R) should be of noninductive type, and rated for 25% of the total power, unless some type of automatic shutoff system is incorporated. The degree of isolation obtainable depends upon the frequency, and the overall design of the hybrid. Typical

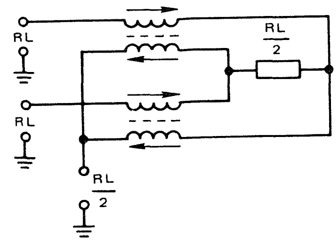



FIGURE 7A

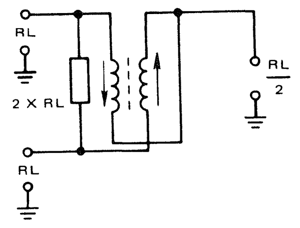



FIGURE 7B

FIGURE 7 — Variations of Basic Hybrid

figures for 2 to 30 MHz operation are 30-40 dB. Figures 8A and B show 4 port "totem pole" structures derived from Figures 7A and 7B. Both can be used with even number of sources only, e.g. 4, 8, 16, etc. For type 8B, it is more practical to employ toroidal multi-turn lines, rather than the straight line alternatives, discussed earlier. The power output with various numbers of inoperative sources can be calculated as follows, if the phase differences are negligible: (Reference 2)

$$P_{out} = \left(\frac{P}{N}\right) N_1$$

where: $P$ = Total power of operative sources
$N$ = Total number of sources
$N_1$ = Number of operative sources

Assuming the most common situation where one out of four amplifiers will fail, 75% of the total power of the remaining active sources will be delivered to the load.

Another type of multiport hybrid derived from Figure 7A is shown in Figure 9. It has the advantage of being capable of interfacing with an odd number of sources or loads.

In fact, this hybrid can be designed for any number of ports. The optimum values of the balancing resistors will vary according to this and also with the number of ports assumed to be disabled at one time. Two other power combining arrangements are shown in Figures 10 and 11.

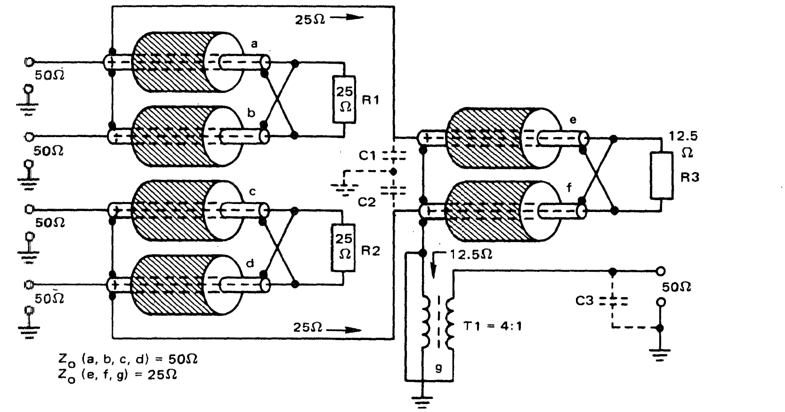



**FIGURE 8A**

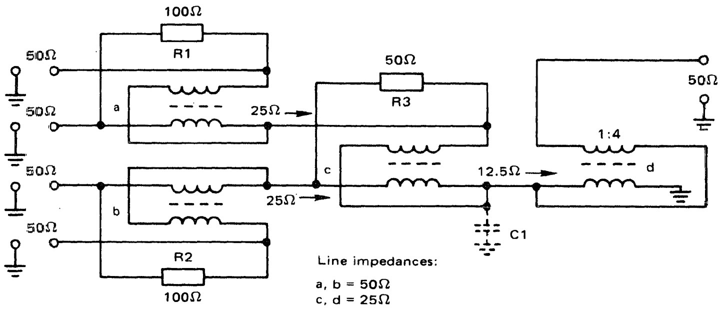



**FIGURE 8B**

**FIGURE 8 — Four Port "Totem Pole" Structure**

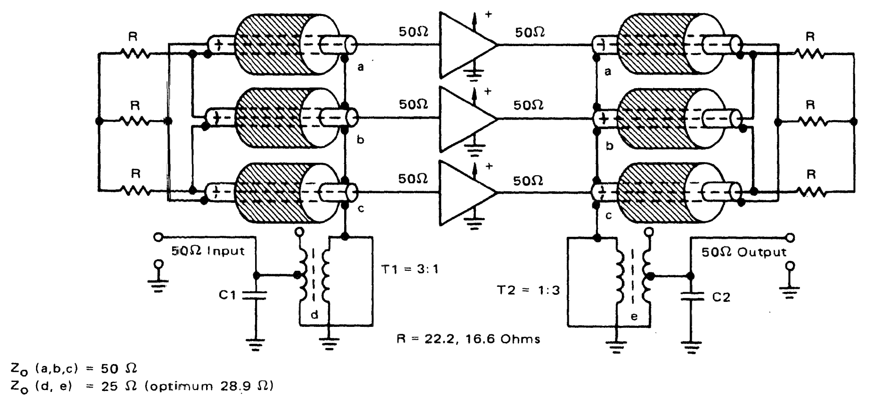
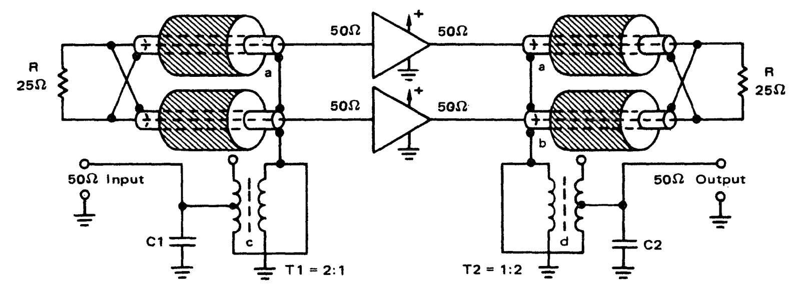
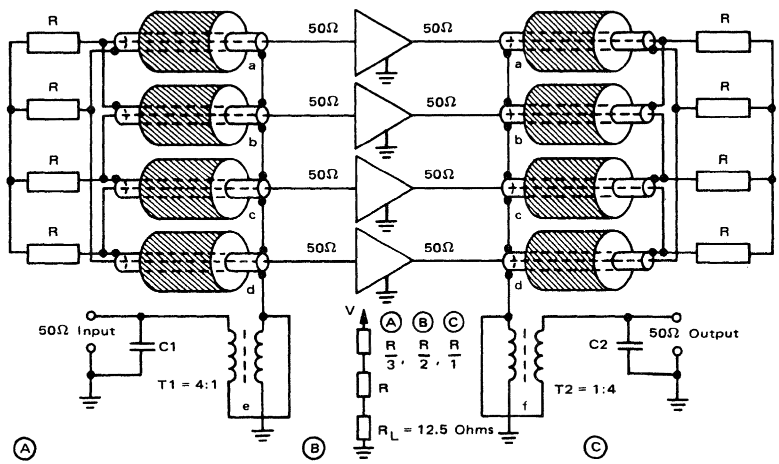



**FIGURE 9 — Three-Port Hybrid Arrangement**




$Z_o$ (a,b) = 50 Ω
$Z_o$ (c,d) = 25 Ω (optimum 35.4 Ω)

**FIGURE 10 – Two-Port Hybrid System**




Ⓐ 1 PORT INOPERATIVE.
Optimum R = 28.3 Ohms

$P_{out} = (P1+P2+P3)-(P_R + P\frac{R}{3})$

Ⓑ 2 PORTS INOPERATIVE.
Optimum R = 25 Ohms

$P_{out} = (P1+P2)-(P_R+P\frac{R}{2})$

Ⓒ 3 PORTS INOPERATIVE.
Optimum R = 18.75 Ohms

$P_{out} = P1-(P_R+P\frac{R}{1})$

P1, P2, P3 = Power at any operative port, $P_R$ = Power dissipated in R, excluding $R_L$.
V = RMS voltage at any 50 Ohm point.
(The phase differences are assumed negligible.)

$Z_o$ (a,b,c,d) = 50 Ω
$Z_o$ (e,f) = 25 Ω (optimum)

**FIGURE 11 – Four-Port Hybrid System**

The isolation characteristics of the four-port output combiner were measured, the data being shown in Table 5. The ferrite sleeves are Stackpole 57-0572-27A, and the transmission lines are made of RG-142/U co-axial cable. The input power dividers described here, employ Stackpole 57-1511-24B ferrites, and the co-axial cable is Microdot 250-4012-0000.

TABLE 5 – Isolation
Characteristics of Four Port Output Combiner

| f (MHz) | Isolation, Port-to-Port (dB) |
|---|---|
| 2.0 | 27.0-29.4 |
| 4.0 | 34.8-38.2 |
| 7.5 | 39.0-41.2 |
| 15 | 32.1-33.5 |
| 20 | 31.2-33.0 |
| 30 | 31.0-33.4 |

The input and output matching transformers (T1 – T2) will be somewhat difficult to implement for such impedance ratios as 2:1 and 3:1. One solution is a multi-turn toroid wound with co-axial cable, such as Microdot 260-4118-000. A tap can be made to the braid at any point, but since this is 25-Ohm cable, the $Z_O$ is optimum for a 4:1 impedance ratio only. Lower impedance ratios will normally require increased values for the leakage inductance compensation capacitances (C1 – C2). For power levels above 500-600 W, larger diameter co-axial cable is desirable, and it may be necessary to parallel two higher impedance cables. The required cross sectional area of the toroid can be calculated according to the $B_{max}$ formulas presented in References 4 and 6.

The 2 to 30 MHz linear amplifier (shown in Figure 13) consists of two 300 W modules (8). This combined amplifier can deliver 600 W peak envelope power. The CW power output is limited to approximately 400 W by the heatsink and the output transformer design.

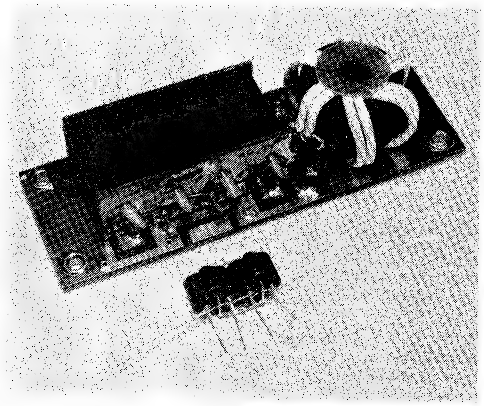


FIGURE 12 – Two-Four Port Hybrids

The one at the lower left is intended for power divider applications with levels to 20 – 30 W. The larger one was designed for amplifier output power combining, and can handle levels to 1 – 1.5 kW. (The balancing resistors are not shown with this unit.)

The power combiner (Figure 13A) and the 2:1 step-up transformer (Figure 13B) can be seen in the upper right corner. The input splitter is located behind the bracket (Figure 13C). The electrical configuration of the hybrids is shown in Figures 7A and 10. Note the loops equalizing the lengths of the co-axial cables in the input and output to assure a minimum phase difference between the two modules.

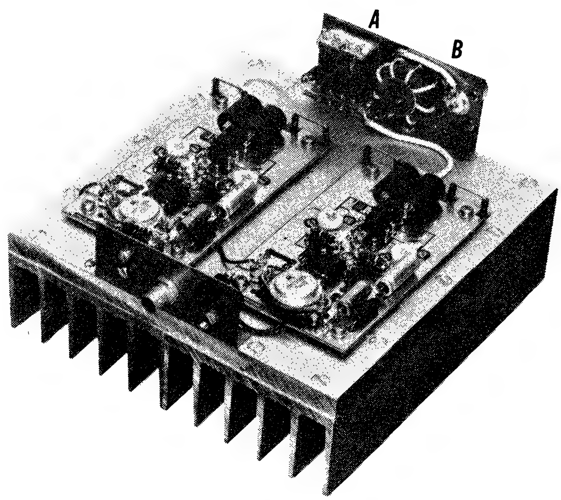
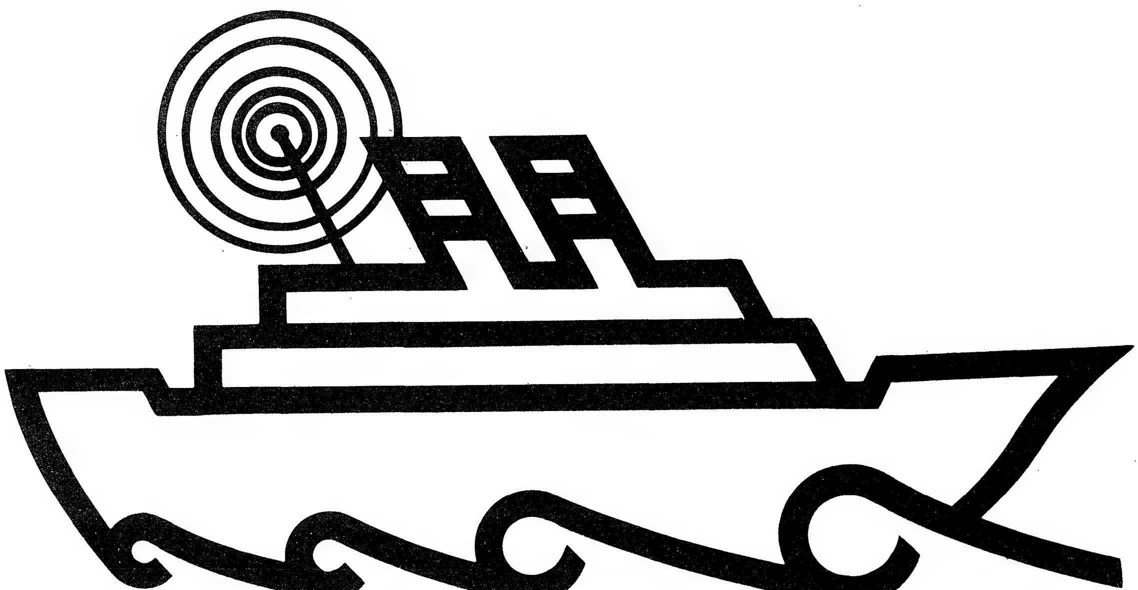



FIGURE 13 – 2 to 30 MHz Linear Amplifier Layout

**REFERENCES**


1. Ruthroff: Some Broad Band Transformers, *IRE, Volume 47,* August 1957.
2. Pizalis-Couse: Broadband Transformer Design for RF Transistor Amplifiers, *ECOM-2989,* U.S. Army Electronics Command, Fort Monmouth, New Jersey, July 1968.
3. Lewis: *Notes on Low Impedance H.F. Broad Band Transformer Techniques,* Collins Radio Company, November 1964.
4. Hilbers: Design of H. F. Wideband Power Transformers, *Philips Application Information #530.*
5. *Philips Telecommunication Review, Volume 30, No. 4,* pp. 137-146, November 1972.
6. Granberg, H.: *Broadband Linear Power Amplifiers Using Push-Pull Transistors,* AN-593, Motorola Semiconductor Products Inc.
7. Granberg, H.: *Get 300 Watts PEP Linear Across 2 to 30 MHz From This Push-Pull Amplifier,* EB-27, Motorola Semiconductor Products Inc.
8. Lefferson: Twisted Wire Transmission Line, *IEEE Transactions on Parts, Hybrids and Packaging, Vol. PHP-7, No. 4,* December 1971.
9. Krauss-Allen: Designing Toroidal Transformers to Optimize Wideband Performance, *Electronics,* August 1973.



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**Semiconductors**
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# 2N6370

## The RF Line

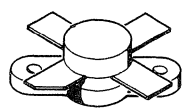
### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily as a driver for high-power linear amplifier stages operating from 2.0 to 30 MHz.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 10 W (PEP)
  Minimum Gain = 12 dB
  Efficiency = 38%
- Intermodulation Distortion @ 10 W (PEP)
  IMD = -30 dB (Max)

**10 W (PEP) – 30 MHz**
**RF POWER TRANSISTOR**
**NPN SILICON**

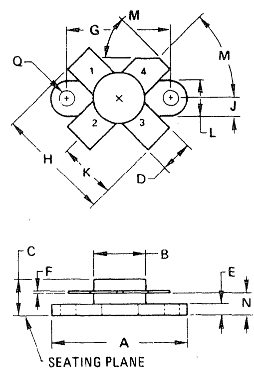
3



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.5 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 20<br>0.114 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07

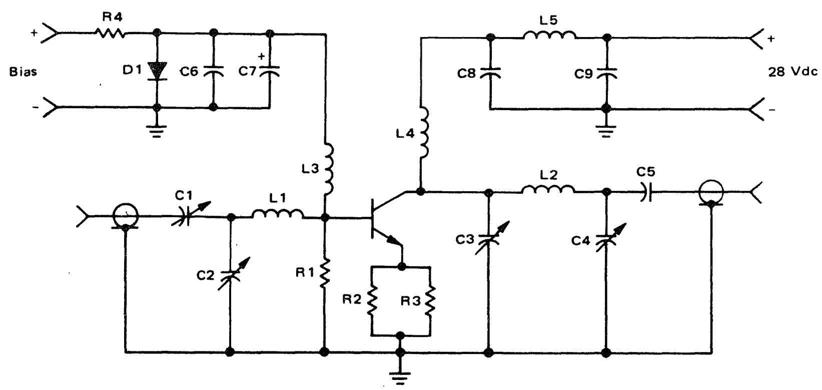
3

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristics | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $V_{BE}$ = 0, $T_C$ +55°C) | $I_{CES}$ | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | 50 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 0.5 Adc, $V_{CE}$ = 15 Vdc, f = 50 MHz) | $f_T$ | 50 | – | MHz |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 40 | pF |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 10 W(PEP), $I_C$ = 470 mAdc Max, $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 12 | – | dB |
| Intermodulation Distortion Ratio (Figure 1)(1) ($P_{out}$ = 10 W(PEP), $I_C$ = 470 mAdc Max, $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -30 | dB |
| Collector Efficiency ($P_{out}$ = 10 W(PEP), $I_C$ = 470 mAdc Max, $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 38 | – | % |

*Indicates JEDEC Registered Data.
(1) To MIL STD 1311 Version A, Test Method 2204, Two Tone, Reference Each Tone

FIGURE 1 – 30 MHz TEST CIRCUIT




| | | | | | |
|---|---|---|---|---|---|
| C1 | 80 – 480 pF | ARCO 466 or equivalent | L2 | 5 Turns, #18 AWG, 1/4" I.D., 5/16" Long (0.13 μH) | |
| C2,C3,C4 | 170 – 780 pF | ARCO 469 or equivalent | L3 | 10 μH | |
| C5 | 0.1 μF | | L4 | 1.0 μH | |
| C6,C9 | 0.01 μF | | L5 | RFC VK200 FERROXCUBE | |
| C7 | 500 μF | TANTALUM or equivalent | R1 | 10 OHMS | 1/2 W ALLEN BRADLEY or equivalent |
| C8 | 2000 pF | UNELCO or equivalent | R2,R3 | 1.5 OHMS | 1/2 W ALLEN BRADLEY or equivalent |
| D1 | 1N4001 | | R4 | 50 OHMS | 1/2 W ALLEN BRADLEY or equivalent |
| L1 | 4 Turns, #18 AWG, 1/2" I.D., 1/4" Long (0.1 μH) | | | | |

ADJUST BIAS FOR $I_{CQ}$ = 10 mA

FIGURE 2 – LINEAR OUTPUT POWER versus FREQUENCY

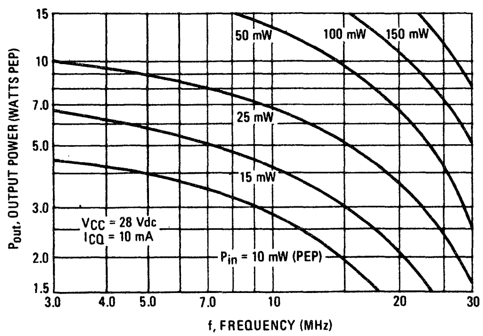



FIGURE 3 – OUTPUT POWER versus INPUT POWER

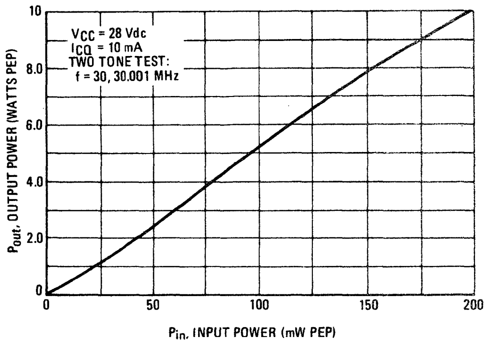



FIGURE 4 – OUTPUT POWER versus INPUT POWER

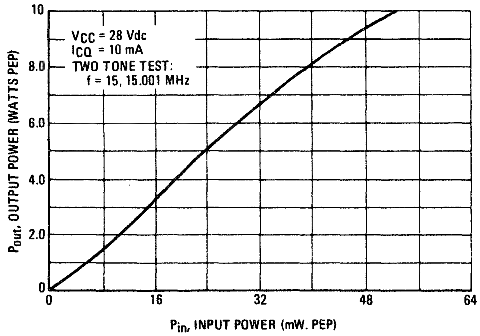



FIGURE 5 – OUTPUT POWER versus INPUT POWER

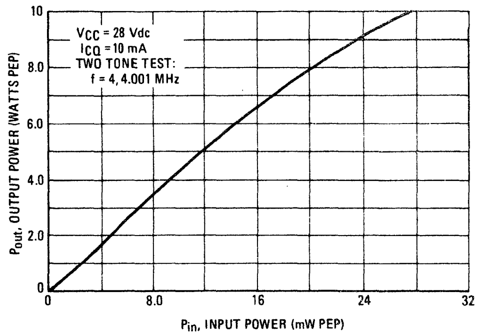



FIGURE 6 – INTERMODULATION DISTORTION versus OUTPUT POWER

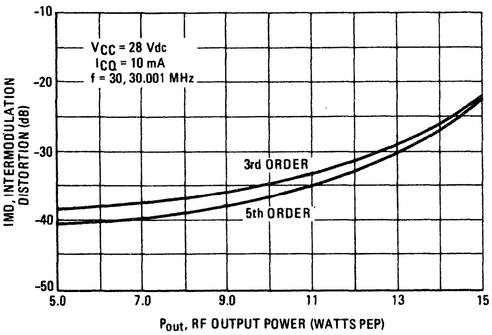



FIGURE 7 – LINEAR OUTPUT POWER versus SUPPLY VOLTAGE

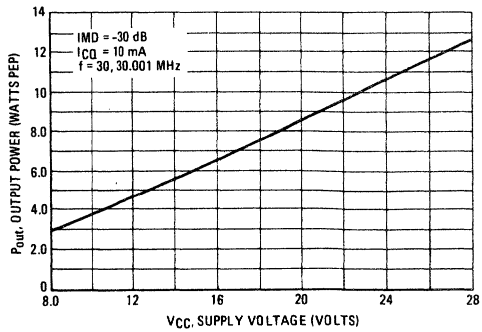


FIGURE 8 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

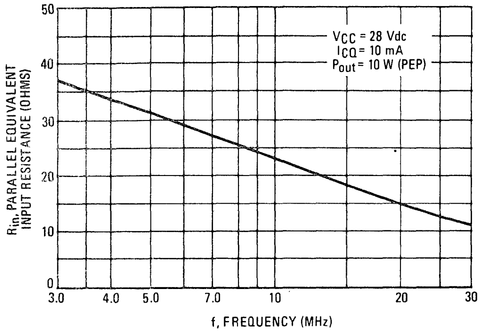



FIGURE 9 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

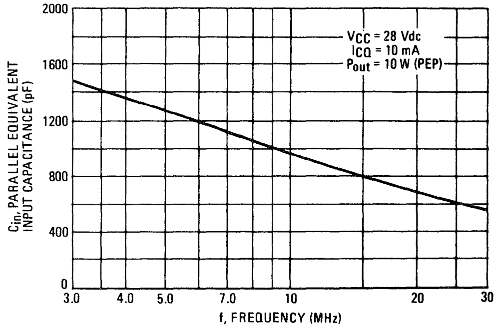



FIGURE 10 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

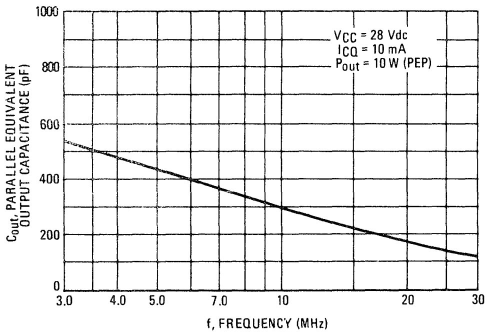



FIGURE 11 – CURRENT GAIN – BANDWIDTH PRODUCT

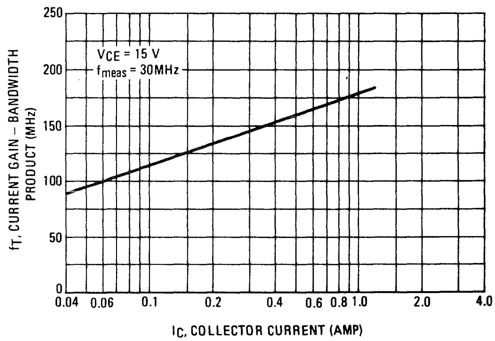



FIGURE 12 – INPUT CAPACITANCE versus EMITTER-BASE VOLTAGE

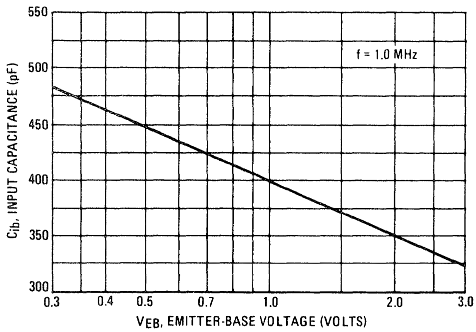



FIGURE 13 – OUTPUT CAPACITANCE versus COLLECTOR-BASE VOLTAGE

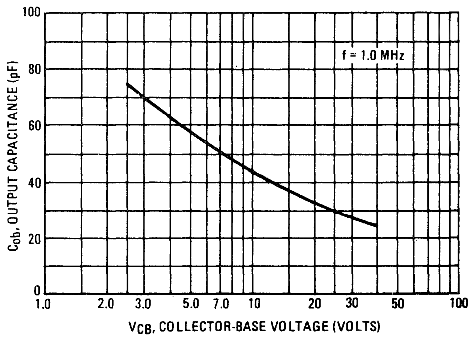


FIGURE 14 – COLLECTOR CURRENT versus BASE-EMITTER VOLTAGE

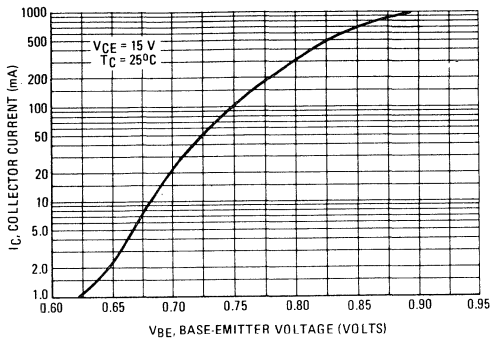



FIGURE 15 – RF POWER DERATING

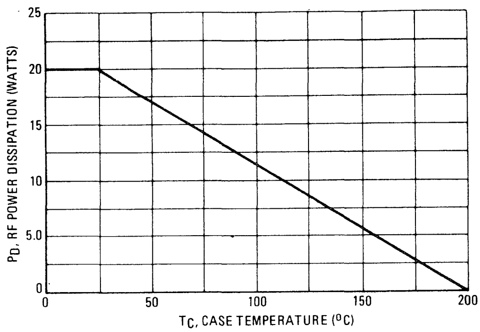
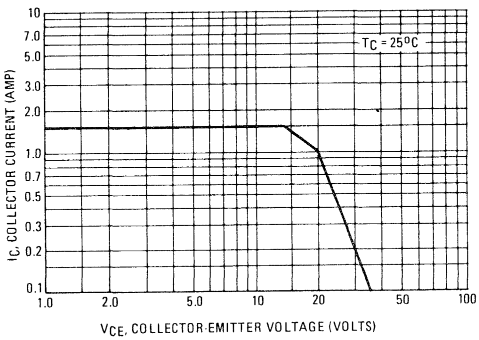



FIGURE 16 – DC SAFE OPERATING AREA



# MOTOROLA Semiconductors

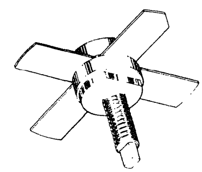
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF401

## The RF Line

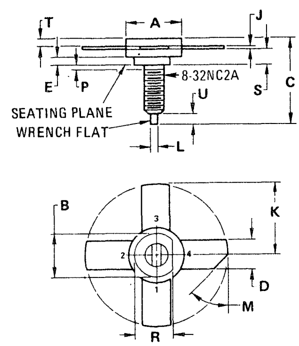
### NPN SILICON RF POWER TRANSISTORS

25 W PEP – 30 MHz
RF POWER
TRANSISTOR
NPN SILICON



. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 75 MHz.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 25 W (PEP)
  Minimum Gain = 13 dB
  Efficiency = 40%
- Intermodulation Distortion at 25 W (PEP)
  IMD = -32 dB (Max)
- Isothermal-Resistor Design Results in Rugged Device




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | $45^{o}$ NOM | | $45^{o}$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

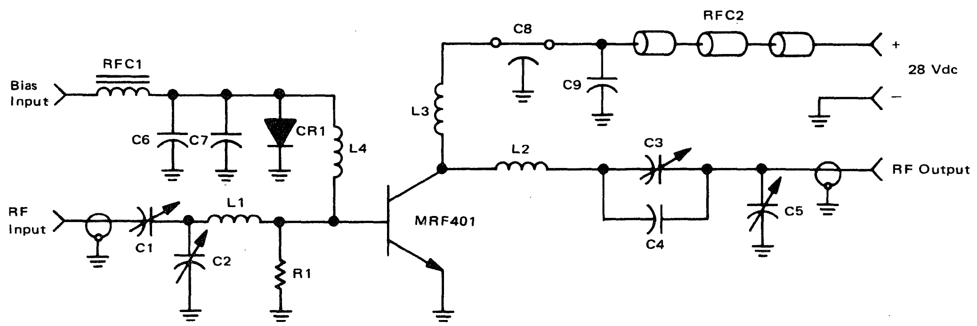
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 3.3 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 50<br>28.6 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as class B or C RF amplifiers.

ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 20 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 65 | 85 | pF |
| **FUNCTIONAL TEST** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 25 Watts PEP, $I_C$ (max) = 1.12 Adc, $V_{CC}$ = 28 Vdc, f = 30 MHz) | $G_{PE}$ | 13 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 25 Watts PEP, $I_C$ (max) = 1.12 Adc, $V_{CC}$ = 28 Vdc, f = 30 MHz) | $\eta$ | 40 | – | – | % |
| Intermodulation Distortion ($P_{out}$ = 25 Watts PEP, $I_C$ = 1.12 Adc, $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IM | – | – | -32 | dB |

**FIGURE 1 – 30 MHz LINEAR TEST CIRCUIT**




C1, C2 – ARCO 469 190-780 pF
C3, C4 – ARCO 464 25-280 pF
C5 – 120 pF Dipped Mica
C6, C7 – 100 μF 15 Vdc
C8 – 680 pF F.T. Allen Bradley
C9 – 1.0 μF 35 V Tantalum
CR1 – IN4997

L1 – 3 Turns #16 0.25" ID
L2 – 6 Turns #16 0.5" ID
L3 – 7 Turns #20 0.38" ID
L4 – 10 μH Molded Choke Delevan
RFC1 – Ferroxcube VK200/20-4B
RFC2 – 3-Ferroxcube 5653065-3B
RF – Input/Output Connectors UG53 A/μ
R1 – 10 Ω 1/2 Watt 10%

Adjust Bias (Base) for $I_{CQ}$ = 20 mA with No RF Applied

FIGURE 2 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

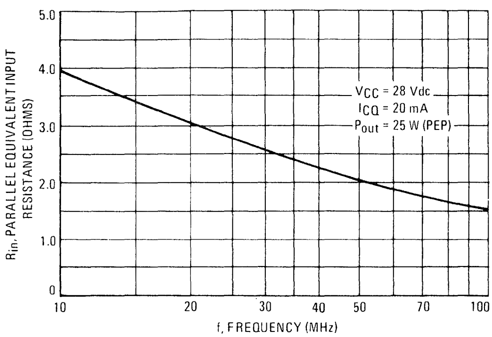



FIGURE 3 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

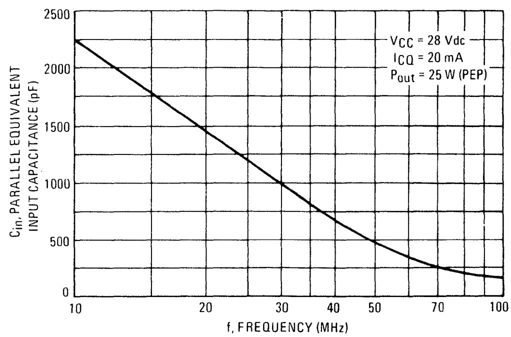



FIGURE 4 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

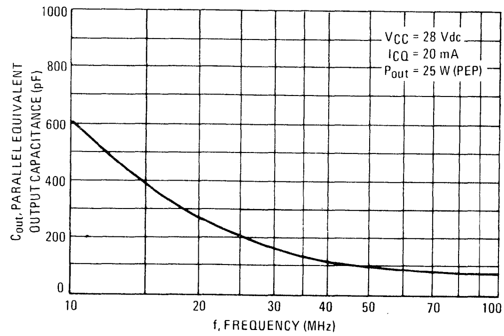



FIGURE 5 – POWER GAIN versus FREQUENCY

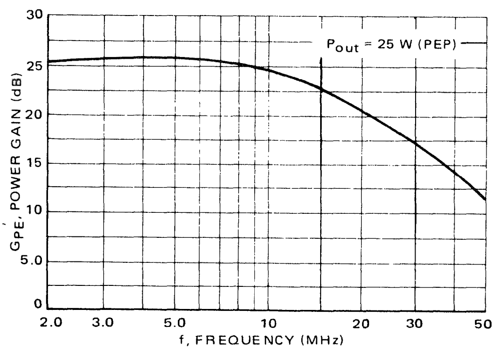
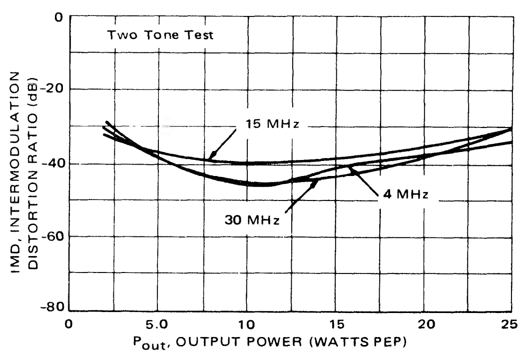



FIGURE 6 – IMD versus POWER OUTPUT



# Measuring the Intermodulation Distortion of Linear Amplifiers

*Prepared by:*
**Helge Granberg**

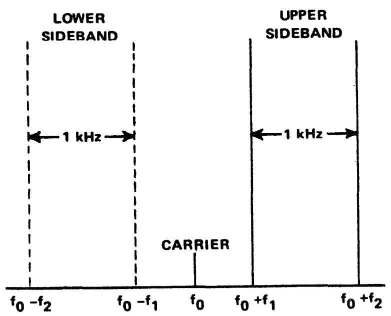
The measured distortion of a linear amplifier, normally called Intermodulation Distortion (IMD), is expressed as the power in decibels below the amplifier's peak power or below that of one of the tones employed to produce the complex test signal.

A signal of three or more tones is used in certain video IMD tests, but two tones are common for HF SSB. The two-tone test signal provides a standard, controlled test method, whereas the human voice contains an unknown number of frequencies of various amplitudes and couldn't be used for accurate power and linearity measurements. Separation of the two tones, for voice operation equipment, may be from 300 Hz to 3 kHz, 1 kHz being a standard adopted by the industry.

### Generation of the Test Signal

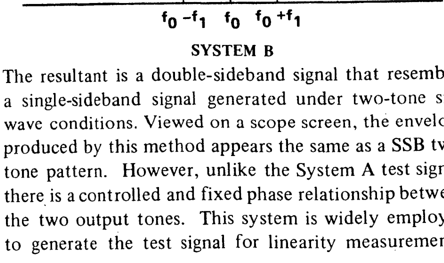
The two-tone IMD test signal can be generated by a number of means of which the following three are the most common:

System A–A two-tone audio signal is formed by algebraically adding two sine wave voltages of equal amplitude which are not harmonically related, e.g., 800 Hz and 1.8 kHz. This two-tone audio signal is fed into a balanced modulator together with an RF carrier, one sideband filtered out, and the resultant further mixed to the desired frequency and then amplified. The system is useful in testing complete SSB transmitters. A commercial transmitter can also be used as a signal source for testing linear amplifiers.




SYSTEM A

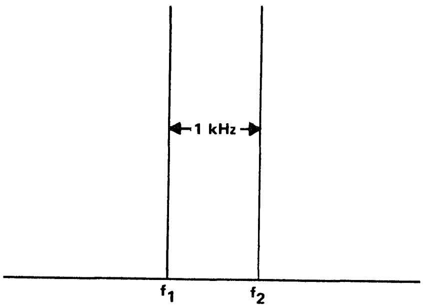
System B–In this method, a signal of approximately 500 Hz is fed into a balanced modulator together with an RF carrier and amplified to the required power level.




SYSTEM B

The resultant is a double-sideband signal that resembles a single-sideband signal generated under two-tone sine wave conditions. Viewed on a scope screen, the envelope produced by this method appears the same as a SSB two-tone pattern. However, unlike the System A test signal, there is a controlled and fixed phase relationship between the two output tones. This system is widely employed to generate the test signal for linearity measurements.

System C–Two equal amplitude RF signals, separated in frequency by 1 kHz, are algebraically added in a hybrid coupler. The isolation between input ports must be high enough to avoid interaction between the two RF signal generators. Short-term stability (jitter) should be




SYSTEM C

less than one part per million at 30 MHz. The carrier is nonexistent as compared to A and B, and the two-tone signal is generated as the RF voltages cancel or add at the rate of their difference frequency according to their instantaneous phase angles. Because no active components are involved, very low IM distortion is achievable. This system is useful in applications where low distortion and low power levels are required.

Except for the position of the carrier in respect to the two tones, displays of the signals produced by systems A, B and C appear identical on a spectrum analyzer screen. Sometimes, however, the suppressed carrier may remain below the noise level of the instrument. Any spectrum analyzer used for SSB linearity measurements must have an IF bandwidth of less than 50 Hz to allow the two closely spaced tones to be displayed with good resolution. Figure 1 shows a low distortion, two-tone envelope displayed on a scope screen. On a spectrum analyzer screen the same signal displays as two discrete frequencies separated by the difference of the audio frequency or frequencies. See figure 2. The display represents the rate at which peak power occurs when the two frequencies are in phase and the voltages add. Thus, one peak contains one-fourth (–6 dB) of the peak envelope power (PEP). An average reading power meter would read the combined power of the tones, or half the PEP, assuming the envelope distortion is negligible. The third order distortion products ($d_3$), fifth order ($d_5$), etc., can be seen on each side of the tones. The actual power (PEP) of each distortion product can be obtained by deducting the number of decibels indicated by the analyzer from the average power. This value may be useful in determining the linearity requirements of the signal source. While the maximum permissible distortion levels of the driver stages in a multi-stage amplifier may be difficult to specify, a 5- to 6-dB margin is usually considered sufficient.

### Types of Distortion

The nonlinear transfer characteristics of active devices are the main cause of amplitude distortion, which is both device and circuit dependent. On the other hand, harmonic and phase distortion, also present in linear amplifiers, are predominantly circuit dependent. Even order harmonics, particularly noticeable in broadband designs, cause the harmonic distortion. Push-pull design will eliminate most of the even-order-caused harmonic distortion and the driver stages, where efficiency is of less concern, can be biased to class A.

Phase distortion can be caused by any amplitude or frequency sensitive components, such as ceramic capacitors or high-Q inductors, and is usually present in multi-stage amplifiers. This distortion may have a positive or negative sign, resulting in occasions where the level of some of the final IMD products ($d_3$ or $d_5$, or both) may be lower than that of the driving signal, due to cancelling effects of opposite phases. Actual levels depend on the relative magnitude of each distortion product present.

From the above it is apparent that the distortion figures presented by the spectrum analyzer represent a combination of amplitude, harmonic and phase distortion.

### Measurement Standards

As indicated earlier, there are two standard methods of measuring the IM distortion:

Method 1 -In military standard (1131 A-2204B), the distortion products are referenced to one of the two tones of the test signal. The maximum permissible IMD is not specified but, numbers like -35 dB are not uncommon in some equipment specifications. However, when this measuring system is employed in industrial applications, the IMD requirement ($d_3$) is usually relaxed to –30 dB. Figure 3 shows the frequency spectrum of IM distortion products and their relative amplitudes for a typical class AB linear amplifier. Biasing the amplifier more toward class B will cause the lower order distortion products to go down and the amplitudes of the higher order products to increase. There is a bias point where the $d_3$ and $d_5$ products become equal resulting in 2–5 dB improvement in the lower order IMD readings.

Method 2–In the proposed EIA standard, the amplitude of the distortion products is referenced to the peak envelope power, which is 6 dB higher in power than that represented by one of the two tones. The amplifier or device indicating a maximum distortion level of –30 dB in Method 1 represents –36 dB with the EIA proposed standard. Conversely, a –30 dB reading with EIA's PEP reference would be –24 dB when measured with the more conservative military method. In practical measurements, the two tones can be adjusted 6 dB down from the zero dB line, and direct IMD readings can be obtained on the calibrated scale of the analyzer. Alternatively, the tone peaks can be set to the zero dB level and 6 dB deducted from the actual reading.

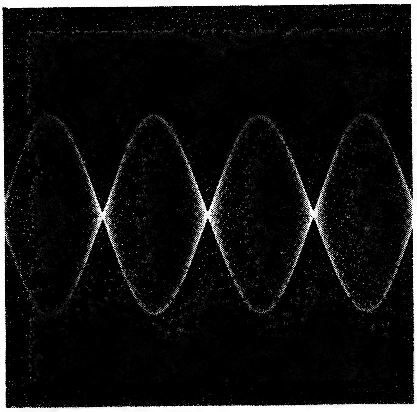


FIGURE 1. Two-tone test pattern generated by A, B or C.

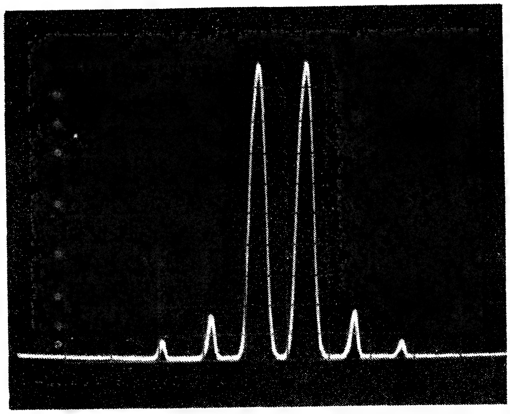


FIGURE 2. Test signal of figure 1 displayed by a spectrum analyzer. 3rd and 5th order distortion products are visible.

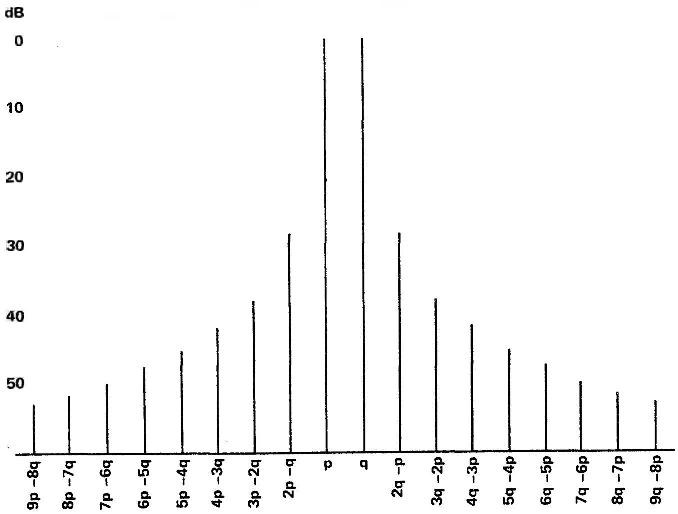



FIGURE 3. Typical distribution of distortion product amplitudes compared to the two fundamental frequency components.

The military standard, with the relaxed –30 dB IMD specification, is employed by most manufacturers of high power commercial transmitters and marine radio base stations. The EIA measuring method is used by the majority of ham radio equipment and CB radio manufacturers. It is also used to measure IMD in various mobile radio applications operating from a 12.5-V nominal dc supply.

Because of the importance to your design, data sheets of the newer generation Motorola devices specify linearity tests appropriate to the expected application of the particular device and test conditions are always indicated.

REFERENCES:

*Pappenfus, Brueue & Schoenike, "Single-Sideband Principles and Circuits," McGraw-Hill.*

*William I. Orr, "Radio Handbook," 18th Edition, Editors and Engineers, Ltd.*

*Stoner, Goral, "Marine Single-Sideband," Editors and Engineers, Ltd.*

*Hooton, "Single-Sideband, Theory and Practice," Editors and Engineers, Ltd.*

# BROADBAND LINEAR POWER AMPLIFIERS USING PUSH-PULL TRANSISTORS

Prepared by:
**Helge O. Granberg**

## INTRODUCTION

Linear power amplifier operation, as used in SSB transmitters, places stringent distortion requirements on the high-power stages. To meet these distortion requirements and to attain higher power levels than can be generally achieved with a single transistor, a push-pull output configuration is often employed. Although parallel operation can often meet the power output demands, the push-pull mode offers improved even-harmonic suppression making it the better choice. The exact amount of even-harmonic suppression available with push-pull stages is highly dependent on several factors, the most significant one being the matching between the two output devices. Nevertheless, even in the worst case the suppression provided in push-pull designs is superior to that of single-ended circuits. Device matching however is not limited to push-pull circuits since it is also required to a lesser degree in parallel transistor designs.

Two linear power amplifier designs are to be discussed in this Application Note. The 80 Watt design is intended for mobile communications systems operating from a 12.5 V power sources. The other supplies 160 W when operated from a 28 V line and it is intended for fix location systems. Both designs cover the 3–30 MHz band and utilize a driver stage to provide a total power gain of about 30 dB. Each amplifier requires some amount of heat-sinking for proper operation. The 28 V amplifier requires a heat-sink with a thermal characteristic of 0.85°C/W while the 12.5 V version uses a heat-sink with a 1.40°C/W thermal resistance. With these heat-sinks, cooling fans are not required for normal conditions, since with speech operation the average power is some 15 dB below peak levels. However, if two-tone bench testing is to exceed more than a duration of a few minutes, a cooling fan should be provided.

To assure ruggedness, engineering models of both amplifiers were subjected to open and short circuit output mismatches for several minutes at full power levels without any apparent damage to any of the transistors. This is very important in most equipment designs to avoid possible downtime for transistor replacements.

## A 28 V, 160 W AMPLIFIER

An amplifier which can supply 160 watts (PEP) into a 50 Ω load with IMD performance of -30 dB or better is shown in the schematic diagram of Figure 1 and photos of Figures 2 and 3. Two 2N5942 transistors are employed in the design. These transistors are specified at 80 watts (PEP) output with intermodulation distortion products (IMD) rated at -30 dB. For broadband linear operation, a quiescent collector current of 60-80 mA for each transistor should be provided. Higher quiescent current levels will reduce fifth order IMD products, but will have little effect on third order products except at lower power levels. Generally, third order distortion is much more significant than the fifth order products.

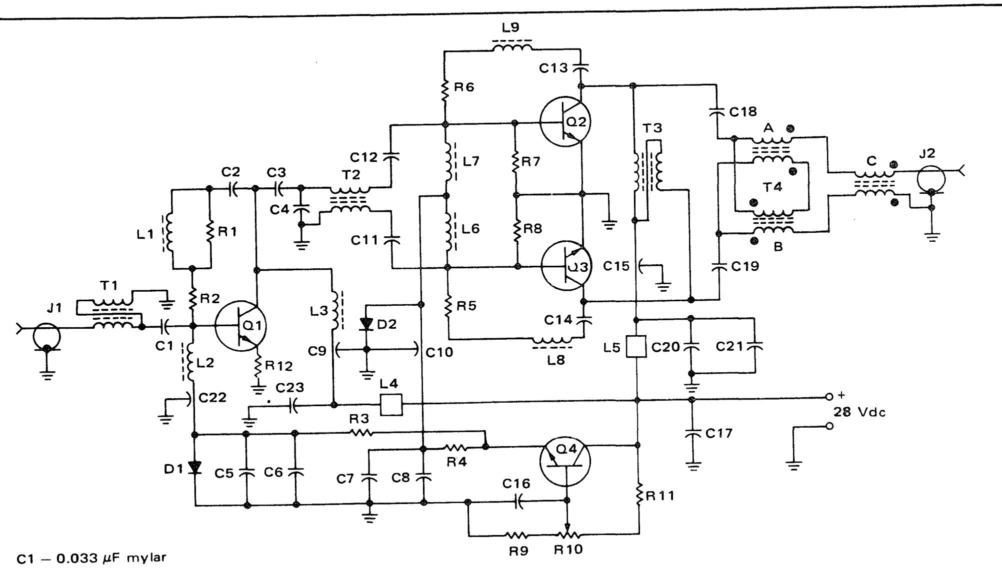
A biasing adjustment is provided in the amplifier circuit to compensate for variations in transistor current gain. This adjustment allows control of the idling current for both the output and driver devices. This control is also useful if the amplifier is operated from a supply other than 28 volts.

Even with the biasing control, it is strongly suggested that the output transistors be beta matched. As with any push-pull design, both dc current gain and power gain at a midband frequency should be matched within about 15-20%. This matching may require more stringent limits if broad-banding is necessary since broad-band operation requires more effective cancellation of even harmonics. In the engineering model used, the transistors were not perfectly matched. Four "similar" pairs were selected from a total of ten randomly chosen 2N5942 transistors. Table I shows the measured harmonic suppression which is degraded by the mismatch in the output transistor parameters. This data was taken with a single frequency test and 80 watts average output.

**TABLE I – HARMONIC SUPPRESSION OF 28 V AMPLIFIER AT FULL OUTPUT POWER**

| Harmonic | | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| Frequency | 3 MHz | -16 dB | -30 dB | -22 dB | -37 dB |
| | 6 MHz | -15 dB | -20 dB | -21 dB | -37 dB |
| | 12 MHz | -16 dB | -24 dB | -22 dB | -34 dB |
| | 30 MHz | -35 dB | -20 dB | -51 dB | -44 dB |

A 2N6370 transistor is employed as a driver. This device is specified at -30 dB IMD when delivering 10 watts (PEP). However, at about 4.5 W (PEP) output, which is the maximum necessary to drive two 2N5942 transistors, the IMD is typically better than -40 dB with Class B biasing. A quiescent collector current level of at least 10-15 mA provides best IMD performance with the 2N6370. Higher current levels will not improve linearity, but will degrade driver efficiency.




C1 – 0.033 μF mylar
C2, C3 – 0.01 μF mylar
C4 – 620 pF dipped mica
C5, C7, C16 – 0.1 μF ceramic
C6 – 100 μF/15 V electrolytic
C8 – 500 μF/6 V electrolytic
C9, C10, C15, C22 – 1000 pF feed through
C11, C12 – 0.01 μF
C13, C14 – 0.015 μF mylar
C17 – 10 μF/35 V electrolytic
C18, C19, C21 – Two 0.068 μF mylars in parallel
C20 – 0.1 μF disc ceramic
C23 – 0.1 μF disc ceramic
R1 – 220 Ω, 1/4 W carbon
R2 – 47 Ω, 1/2 W carbon
R3 – 820 Ω, 1 W wire W
R4 – 35 Ω, 5 W wire W
R5, R6 – Two 150 Ω, 1/2 W carbon in parallel
R7, R8 – 10 Ω, 1/2 W carbon
R9, R11 – 1 k, 1/2 W carbon
R10 – 1 k, 1/2 W potentiometer
R12 – 0.85 Ω (6 5.1 Ω or 4 3.3 Ω 1/4 W resistors in parallel, divided equally between both emitter leads)

T1 – 4:1 Transformer, 6 turns, 2 twisted pairs of #26 AWG enameled wire (8 twists per inch)
T2 – 1:1 Balun, 6 turns, 2 twisted pairs of #24 AWG enameled wire (6 twists per inch)
T3 – Collector choke, 4 turns, 2 twisted pairs of #22 AWG enameled wire (6 twists per inch)
T4 – 1:4 Transformer Balun, A&B – 5 turns, 2 twisted pairs of #24, C – 8 turns, 1 twisted pair of #24 AWG enameled wire (All windings 6 twists per inch). (T4 – Indiana General F624-19Q1, – All others are Indiana General F627-8Q1 ferrite toroids or equivalent.)

**PARTS LIST**

L1 – .33 μH, molded choke
L2, L6, L7 – 10 μH, molded choke
L3 – 1.8 μH (Ohmite 2-144)
L4, L5 – 3 ferrite beads each
L8, L9 – .22 μH, molded choke

Q1 – 2N6370
Q2, Q3 – 2N5942
Q4 – 2N5190
D1 – 1N4001
D2 – 1N4997
J1, J2 – BNC connectors

**FIGURE 1 – 160 Watt (PEP) Broadband Linear Amplifier**

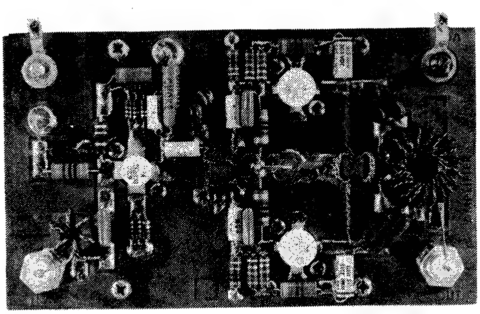


**FIGURE 2 – Photo of 28 V Linear Amplifier**

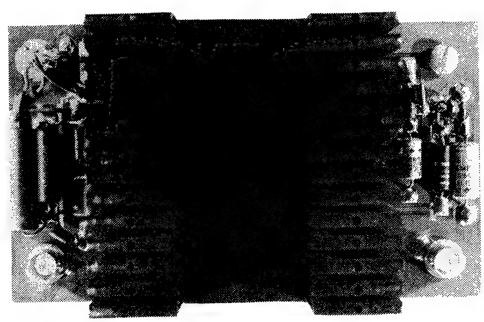


**FIGURE 3 – Photo of Back Side of 28 V Linear Amplifier**

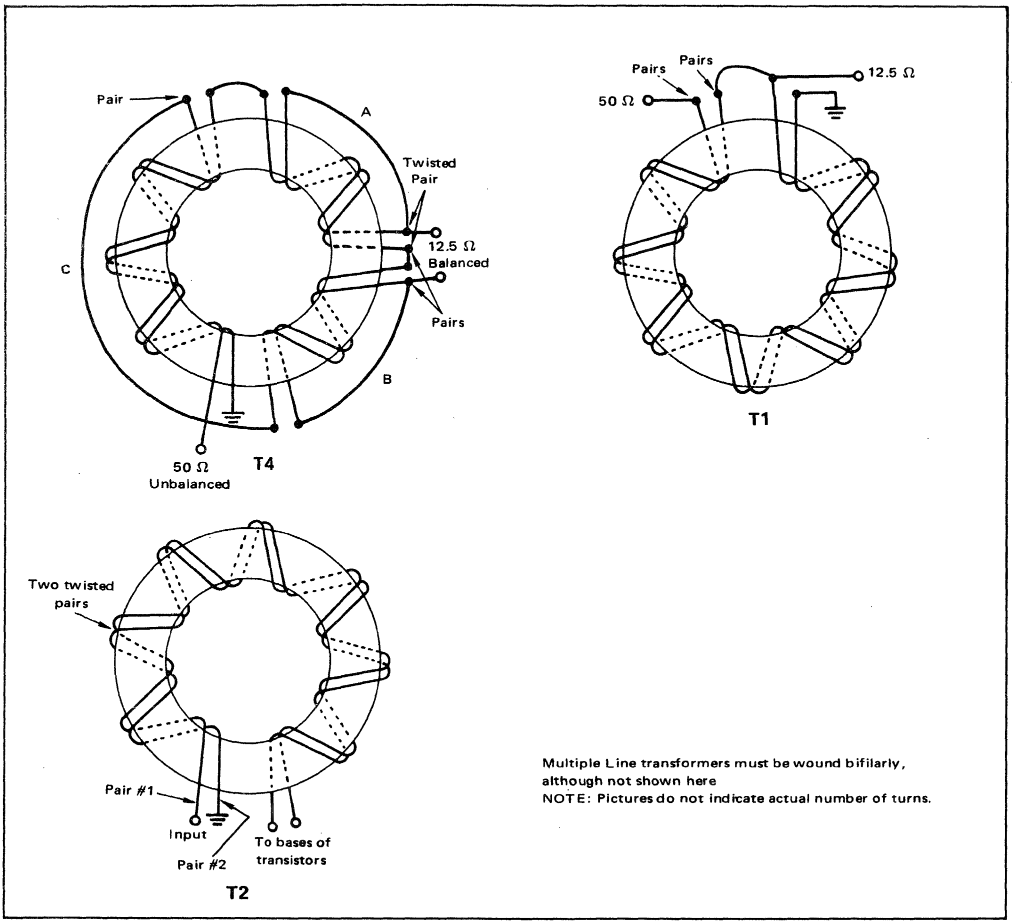



**FIGURE 4 – Transformer Details for 28 V Linear Amplifier**

### Feedback

To compensate for variations in output with changes in operating frequency, negative voltage feedback is employed on both the final amplifier and driver stages. At the low end of the desired frequency band, approximately 4.5 dB of feedback is introduced in the final stage and 15 dB in the driver stage. With this feedback and the feedback networks shown in the schematic diagram, Figure 1, a total gain variation of 0.5 dB was measured on an engineering prototype amplifier over a 3-30 MHz range. The total gain differential in three identical amplifiers constructed for evaluation was less than 1.5 dB.

### Transformers Employed

In order to achieve the desired broadband response, transmission line-type transformers were employed for coupling and signal-splitting. These transformers utilize twisted-pair windings and toroidal cores. Transformers T1, T2 and T3 have turn ratios of 4:1, 1:1 and 1:4 respectively. Additional information on these transformers can be found in the references. A short description of each of the transformers will follow.

Transformer T1 provides an impedance transformation to match the 50 Ω source to the low impedance level required at the base of Q1. This transformer consists of six turns of two twisted pairs wound on a toroidal core. The two pairs (four separate wires), are twisted together and the two wires from each original pair are soldered together at each end. Each pair thus connected is shown as a single wire in Figure 4. The pairs can easily be identified by choosing wires with two different colors of insulation.

Transformer T2 is a 1:1 Balun consisting of six turns of two-twisted pairs of wire (four wires total). As shown in Figure 4 each of the pairs is treated as a single wire.

Transformer T3 consists of four turns of two twisted pairs. Again both wires of each pair are soldered together at each end.

Transformer T4 is a 1:4 ratio unbalanced to balanced unit with three separate windings.

A lumped-constant equivalent conventional transformer diagram of transformer T4 is shown in Figure 5. The two windings in a single twisted pair are indicated by similar capital and lower case letters (i.e. windings A and a). The output line of the balun is in the same direction as windings A and B while the grounded line is in the opposite direction from the winding it is connected to. Windings A, a, B and b consist of 5 turns of two twisted pairs while C and c are formed from eight turns of a single pair. Connections are shown in Figure 4. The three windings are bifilar wound, although for simplicity the figures do not show this.

Referring to Figure 5 the equivalent connection diagram of T4, it can be seen that the sum of the voltages across c and C should be equal to the voltage across windings DE. From this, winding cC (a twisted pair) should have twice as many turns as twisted pairs aA and bB. Deviations of about 10-20% from the 2:1 ratio do not produce noticeable effects.

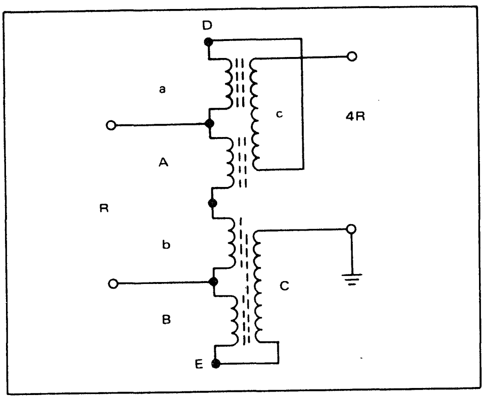



**FIGURE 5 – Equivalent Lumped Element Form of T4.**

The ferrite core used for T4 in the parts list of Figure 1 has a specified maximum flux density of about 100 gauss. The flux density may be computed from equation 1.

$$\text{Bmax} = \frac{V \times 10^8}{4.44\ fnA} \quad \text{gauss} \qquad (1)$$

where:

V = RMS voltage across the winding = 89
f = frequency in Hertz = $3 \times 10^6$
n = number of turns (windings Aa and Bb only. Windings Cc cancel each other) = 20
A = cross sectional area of Toroid in $Cm^2$ = 0.25
$4.44 = 2\pi \times 0.707$

therefore:

$$\text{Bmax} = \frac{89 \times 10^8}{4.44 (3 \times 10^6)\ 20\ (.25)} = 133 \text{ gauss}$$

Despite this slight overrating, this density is not excessive.

## Amplifier Performance

The data shown in the following curves was obtained from measurement performed on an engineering model of the 28 V 160 Watt (PEP) amplifier.

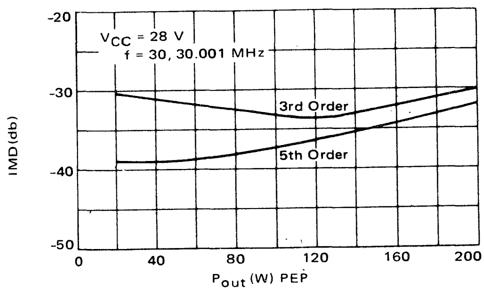



**FIGURE 6 – IMD as a Function of Output Power for 28 V Amplifier**

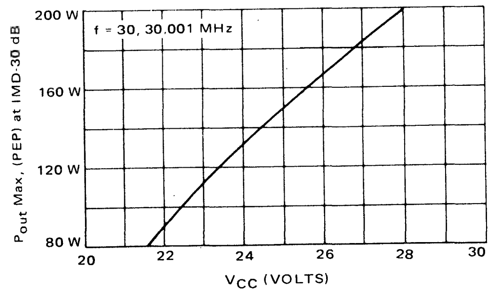



**FIGURE 7 – Output Power for -30 dB IMD as a Function of $V_{CC}$ for 28 V Amplifier**

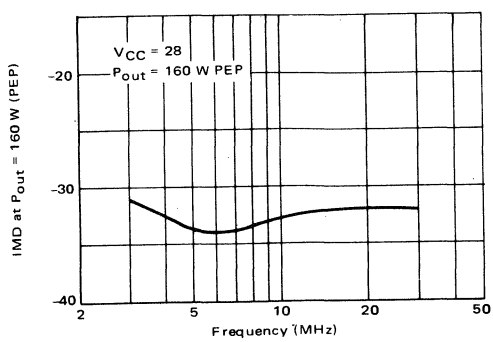



**FIGURE 8 – IMD versus Frequency**

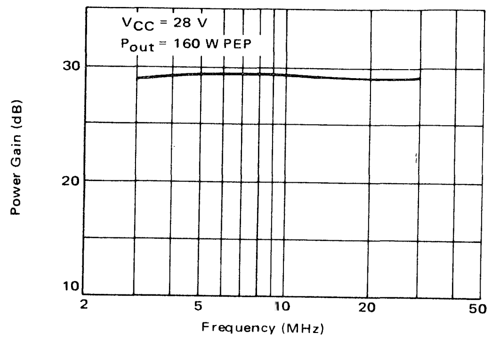



**FIGURE 9 – Power Gain versus Frequency**

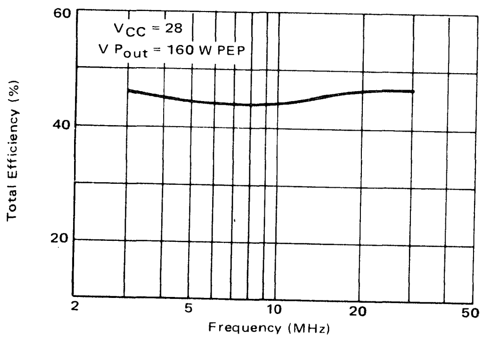



**FIGURE 10 – Total Efficiency versus Frequency**

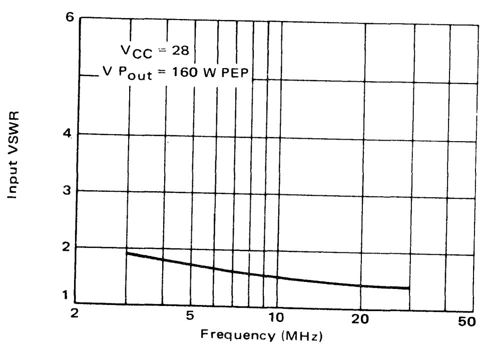



**FIGURE 11 – VSWR versus Frequency**

## AN 80 WATT (PEP) 12.5 – 13.6 V AMPLIFIER

To complement the 28 Volt amplifier discussed previously, a second amplifier designed for 12 V operation was constructed and evaluated. This amplifier is shown in Figures 12, 13 and 14. It utilizes a 2N6367 and a pair of 2N6368 transistors. The 2N6367 transistor is employed as a driver and is specified for up to 9 watts (PEP) output. In the amplifier design the driver must supply only 5 watts (PEP) at 30 MHz with a resulting IMD performance of about -37 to -38 dB. At lower operating frequencies, drive requirements drop to the 2-3 Watt (PEP) range and IMD performance improves to better than 40 dB. The 2N6367 data sheet suggests a quiescent collector current of 35 mA, but it was found that increasing this to 40 mA yielded somewhat better linearity in broadband operation.

Two 2N6368 transistors are employed in the final stage of the transmitter design in a push-pull configuration. These devices are rated at 40 Watts (PEP) and -30 dB maximum IMD, although -35 dB performance is more typical for narrow band operation.

The 2N6368 data sheet suggests a quiescent collector current level of 50 mA, but a level of 60 mA for each transistor was used in this design for improved linearity.

Without frequency compensation, the completed amplifier can deliver 90 Watts (PEP) in the 25-30 MHz band with IMD performance down -30 dB. If only the power amplifier stage is frequency compensated, 95 Watts (PEP) can be obtained at 6-10 MHz.

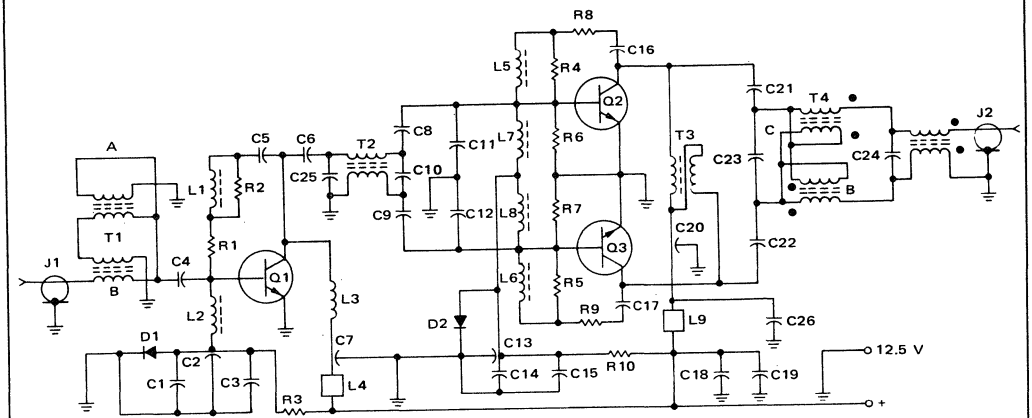
### Gain Compensation

Negative collector-to-base feedback is employed in both the driver and output stages for gain compensation. The feedback networks consist of: a) a dc blocking capacitor, b) a series resistor, to limit the amount of feedback at the low frequencies and c) a series inductor with a parallel resistor to determine the feedback slope.

In general, the use of negative feedback lowers the input impedance, and reduces the gain of the amplifier. However, it also improves the linearity since some of the output signal is fed back to the input and reamplified, tending to cancel the distortion originally generated. This is only true at the low frequencies where the phase errors are small. The phase error is caused by reactive elements in the feedback path. Since the basis for the compensation is to introduce more feedback at low frequencies, it will also equalize the input impedance to some degree. This, in turn, should result in a lower VSWR over the band.

The following two tables illustrate the affect of compensation on the final amplifier stage. This data was taken with a 9:1 ratio transformer connected between 50 Ω source and the input balun to the final stage.

From this table it can be seen that efficiency is reduced by applying compensation. For this reason only 3 dB of compensation was utilized on the final stage. The driver stage, where efficiency is not of primary concern, was actually over compensated. This stage has a gain of 16 dB at 30 MHz but only 13 dB at 3 MHz.




C1, C14, C18 – 0.1 μF ceramic.
C2, C7, C13, C20 – 0.001 μF feed through.
C3 – 100 μF/3V.
C4, C6 – 0.033 μF mylar
C5 – 0.0047 μF mylar.
C8, C9 – 0.015 and 0.033 μF mylars in parallel.
C10 – 470 pF mica.
C11, C12 – 560 pF mica.
C15 – 1000 μF/3 V
C16, C17 – 0.015 μF mylar
C19 – 10 pF 15 V
C21, C22 – two 0.068 μF mylars in parallel.
C23 – 330 pF mica
C24 – 39 pF mica
C25 – 680 pF mica
C26 – .01 μF ceramic

R1, R6, R7 – 10 Ω, 1/2 W carbon.
R2 – 51 Ω, 1/2 W carbon
R3 – 240 Ω, 1 wire W
R4, R5 – 18 Ω, 1 W carbon
R8, R9 – 27 Ω, 2 W carbon
R10 – 33 Ω, 6 W wire W

L1 – 0.22 μh molded choke
L2, L7, L8 – 10 μh molded choke
L5, L6 – 0.15 μh
L3 – 25 t, #26 wire, wound on a 100 Ω, 2 W resistor. (1.0 μh)
L4, L9 – 3 ferrite beads each.

T1 – 2 twisted pairs of #26 wire, 8 twists per inch. A = 4 turns, B = 8 turns. Core- -Stackpole 57-9322-11, Indiana General F627-8Q1 or equivalent

T2 – 2 twisted pairs of #24 wire, 8 twists per inch, 6 turns. (Core as above.)

T3 – 2 twisted pairs of #20 wire, 6 twists per inch, 4 turns. (Core as above.)

T4 – A and B = 2 twisted pairs of #24 wire, 8 twists per inch. 5 turns each. C = 1 twisted pair of #24 wire, 8 turns. Core - - Stackpole 57-9074-11, Indiana General F624-19Q1 or equivalent.

Q1 – 2N6367
Q2, Q3 – 2N6368

D1 – 1N4001
D2 – 1N4997

J1, J2 – BNC connectors

**FIGURE 12 – Schematic Diagram of 12.5 V Amplifier**

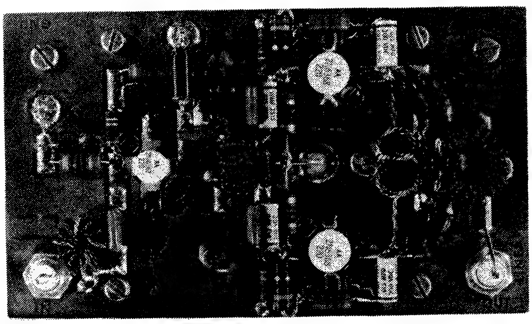


**FIGURE 13 – Photo of Top View of 12.5 V Linear Amplifier**

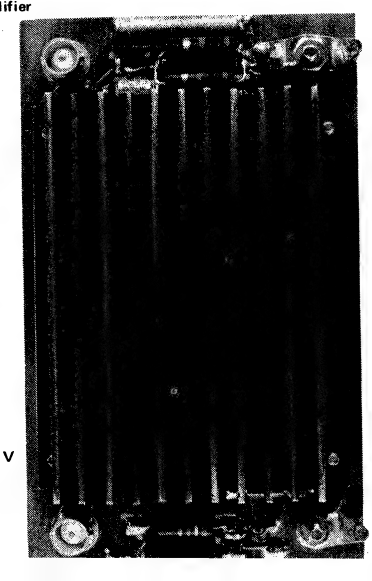


**FIGURE 14 – Photo of Bottom of 12.5 V Linear Amplifier**

**TABLE II – PERFORMANCE OF 12.5 V OUTPUT STAGE WITH AND WITHOUT GAIN COMPENSATION**

| With Feedback | GPE | EFF | IMD | VSWR |
|---|---|---|---|---|
| 3 MHz | 16 dB | 45.5% | -30 dB | 1.6 |
| 12 MHz | 15.3 dB | 46.5% | -31 dB | 2.1 |
| 30 MHz | 12 dB | 43.0% | -31 dB | 1.05 |

| Without Feedback | GPE | EFF | IMD | VSWR |
|---|---|---|---|---|
| 3 MHz | 19.2 dB | 48.0% | -26 dB | 6.5 |
| 12 MHz | 16.2 dB | 46.8% | -30 dB | 2.4 |
| 30 MHz | 12.5 dB | 43.0% | -33 dB | 1.05 |

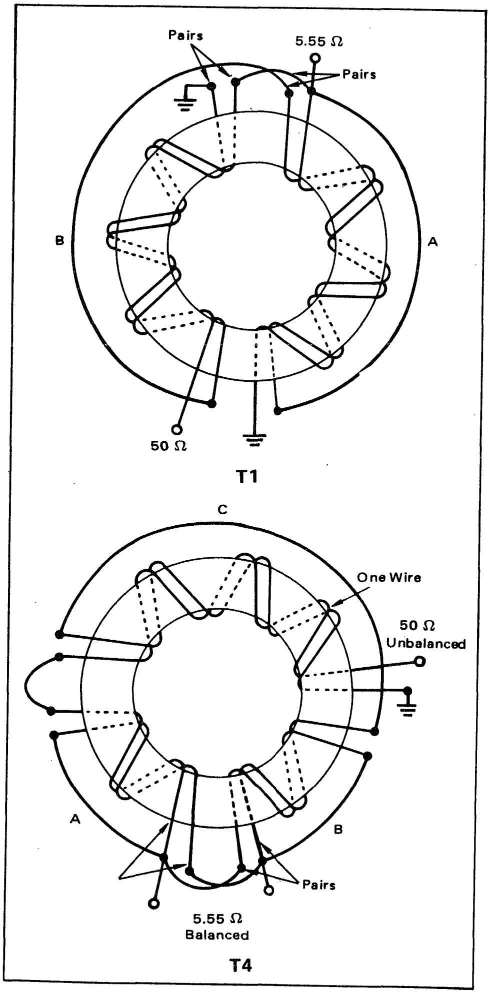



**FIGURE 15 – Transformer Details for 12.5 V Linear Amplifier (See Figure 4)**

Transformer T1 consists of two twisted pairs of wires which can be wound on either a single or two separate toroids. In the two core approach, both windings have an equal number of turns (four). If a single core is utilized, winding Aa uses four turns while winding Bb uses eight turns. These lines must be wound bifilar on the core. See Figure 15. The single core approach was used in the engineering model.

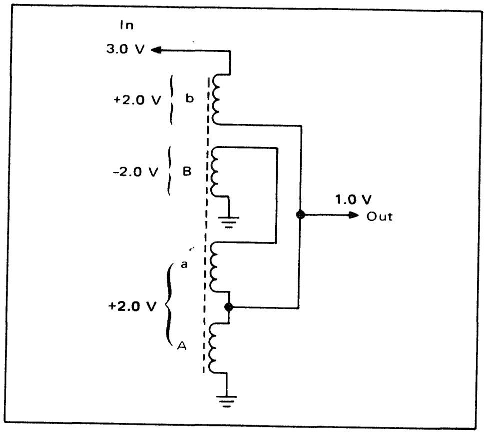



**FIGURE 16 – Equivalent Lumped Element Form of T1**

A lumped-constant equivalent conventional transformer diagram of transformer T1 is shown in Figure 16. Examination reveals that since winding B is directly in parallel with the series combination of aA, line Bb must have twice the number of turns as winding Aa. (The lower case and capital letters refer to the two wires in a given twisted-pair). As an example of the voltage relationships for the various windings in this transformer, an arbitrary 3 V input has been shown in the Figure. It can be seen that the voltages generated across windings b and B are out of phase and cancel each other. Therefore, the resulting output is 1 V (3 V-2 V).

This transformer may be considered as a combination of a 4:1 ratio transformer (aA) and a 1:1 balun (bB), where the balun performs the voltage subtraction.

Transformer T2 consists of two twisted pairs on a single core. Both wires of each pair are soldered together at each end. See Figure 15.

Transformer T3 also uses two twisted pairs wound on a single core. Each pair is treated as a single wire by soldering the two wires at each end.

Transformer T4 uses three separate bifilar windings on a single core. Windings aA and bB are balanced while Cc is unbalanced. Both aA and bB utilize five turns and Cc uses eight turns. This is the nearest whole number of turns possible to the desired ratio of 1:1.5 for winding Aa and

Bb to winding cC. Deviations of 10-20% of this ratio are allowable without noticeable effects.

Figure 17 shows the lumped equivalent transformer of

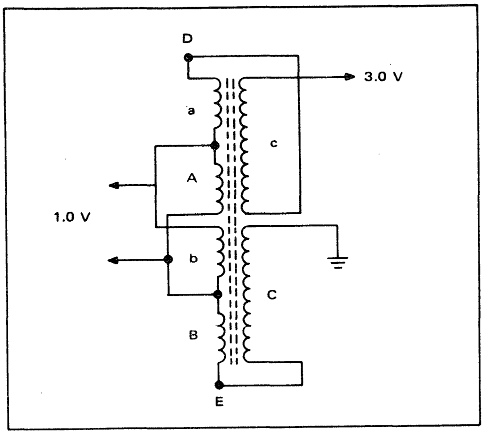



FIGURE 17 – Equivalent Lumped Element Form of T4

T4 and the ratio of voltages on the various windings if one volt is applied to the input. It can be seen that the voltage developed across c and C must equal the voltage between points D and E on the diagram. Since windings A and b are paralleled and connected to the input, they see one volt. Thus the voltage from point D to point E would be 3 V (1 V from A and b plus 1 V from winding a plus 1 V from winding B). Therefore, the output voltage is 3.0 volts and the voltage across winding c = -1.5 V and winding C = 1.5 V.

When using twisted-pair transmission line transformers, windings with four or more pairs should be avoided as it is difficult to twist such lines uniformly.

A second amplifier was evaluated with T4 replaced by a balun and an unsymmetrical 1:9 ratio transformer. Performance results were very similar to that obtained from the first version except that much more high frequency compensation was necessary. This was required because it is difficult to obtain the low characteristic impedance required for the balun. For this reason capacitors C10, C11, C12 and C25 were unusually large in value.

**Performance**

Typical performance of the 12.5 volt linear amplifiers is provided in the following curves. A calibration curve for use to correlate low frequency readings on a power meter is also given in Figure 24.

The harmonic suppression measurements taken at full output power levels with a single tone test are illustrated in Table II. This data suggests that a suitable low-pass filter between the amplifier output and the antenna will be required to meet harmonic suppression requirements. This filter's necessity is common to most broadband amplifier designs.

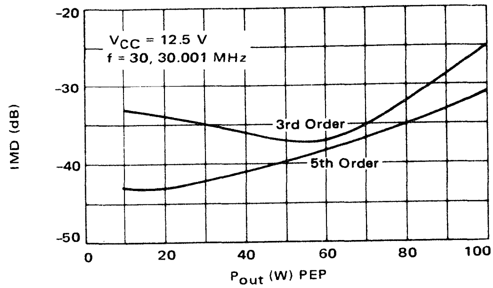



FIGURE 18 – IMD as a Function of Output Power For Push-Pull Linear Amplifier

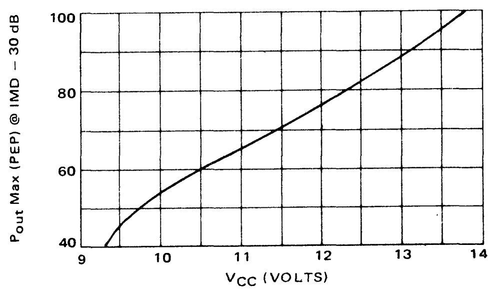



FIGURE 19 – Maximum Output Power @ -30 dB IMD versus $V_{CC}$ for 12.5 V Power Amplifier

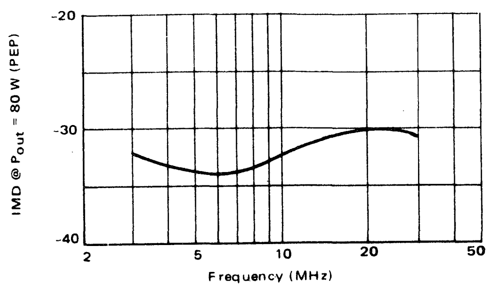



FIGURE 20 – IMD versus Frequency

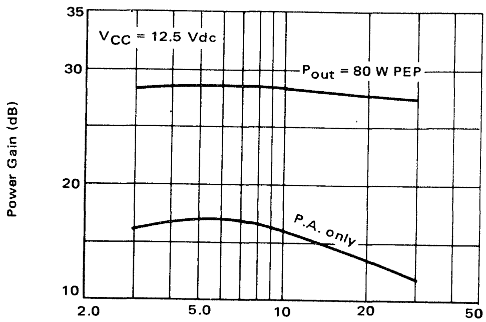



FIGURE 21 – Power Gain versus Frequency

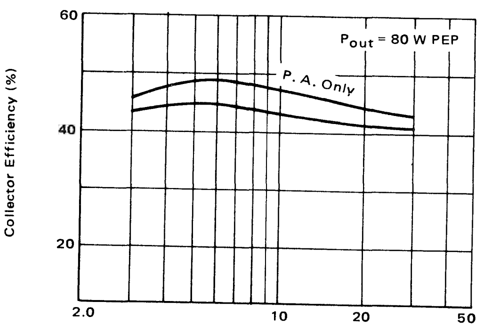



FIGURE 22 – Efficiency versus Frequency

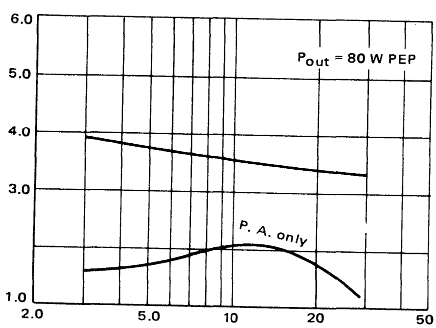



FIGURE 23 – VSWR versus Frequency

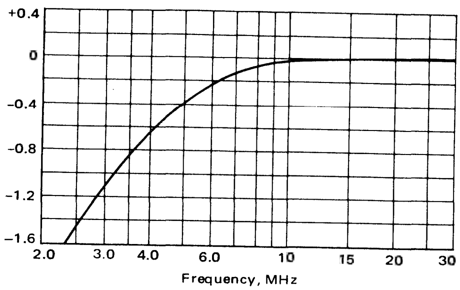



FIGURE 24 – Response of H.P. 431-432 Power Meters at Low Frequencies

**Transformer Data**

As with the 28 V amplifier, transmission line type transformers are employed throughout the 12 V design. Although this type of transformer does not provide optimum impedance match, it is easy to duplicate for consistant performance results. A similar amplifier was constructed with a standard 2:1 ratio coupling transformer instead of the 1:1 ratio balun (T2). This amplifier featured a 40-60% improvement in VSWR at all frequencies while gain and IMD were basically unchanged from the performance of the model using transmission line type transformers.

Splitting the compensating capacitor for transformer T2 into three parts (C10, C11 and C12) will result in considerably lower IMD at higher frequencies. Capacitors C11 and C12 should be well matched and therefore should be either ±5% or better tolerance fixed value units, or variable capacitors such as Arco 466 and 469.

Two factors must be considered in the choice of toroidal core materials. The first is core losses. The second is the power handling capability which is limited by both magnetic saturation and heat generation.

For the input transformer (T1) core losses are of primary concern. For the material chosen in this design, a loss factor of 1-2 mW/cm$^3$ at 3 MHz is typical. This increases to 5-10 mW/cm$^3$ at 30 MHz. For the size of core used in T1, a maximum core loss of 1.5-7.0 mW can be expected. While this figure seems negligible, it is advantageous to use the smallest practical sized core for the input transformer consistent with the wire size and required number of turns.

Conversely the core of the output transformer (T4) should be as large as possible to be able to handle the required power levels and remain in the linear operating region of the materials' B-H curve. If the core is operated near the saturation region of the core material, distortion will be generated on the carrier and envelope. This saturation occurs first at low frequencies. However, core heating due to losses is most prevalent at higher frequencies, being a function of flux density and operating frequency. The maximum recommended flux density for a 1/2" O.D. toroid (such as Indiana General F627-8 or Stackpole 57-9322),

is 45 to 70 gauss. From the B-H curves it can be seen that this is well into the linear region.

For the 12-volt amplifier, a flux density of roughly 180 gauss would be required for a 1/2" O.D. core. Use of a larger core reduces the density to about 130 gauss. As stated in the 28 V amplifier section, although this is in excess of the 100 gauss limit suggested for the particular core type, it was not found to be excessive. In fact, some of the 1/2" O.D. toroids were tested at three to four times the maximum recommended flux density, and then compared to a larger toroid of the same material. The distortion in each core was small enough not to be noticed in an oscilloscope. However, there was some amount of heat generated in the small toroid at the high frequencies. Excessive heating is the primary problem that one should be first concerned about.

As a rule of thumb, the required minimum transformer inductance can be determined to have at least 4-5 times the reactance of the high impedance port at the lowest operating frequency. This means that for T4, the reactance would be 250 ohms, which corresponds to roughly 14 $\mu$H at 3 MHz

Employing a different wire size or wire with a different thickness of dielectric or changing the number of twists per inch will alter the line impedance. However, this is one of the least critical points in the design of broadband linear amplifiers and will mainly affect the amount of high frequency compensation required. The variations in the transistor input and output impedance over a decade frequency range are several times larger than the changes in transformer impedance due to wire sizes or twist variations. Although compromises in matching are necessary to tune the wide frequency range, they are most serious in the output stage where a mismatch can significantly degrade total linearity.

The maximum theoretical linear output powers for the 28 V and 12.5 V amplifiers would be 120 W and 50 W respectively, when 4:1 and 9:1 output transformers are employed.

However, due to stray inductances in the circuit, and line impedances usually being higher than optimum, the actual impedance ratios of the transformers will be somewhat higher.

Thus, if the phase and even harmonic distortions are minimized it is possible to obtain higher power levels with fairly low IMD readings despite slight flat-topping of the envelope.

**Construction Notes (12.5 V version)**

The circuit board for both amplifier designs is made of two-sided copper-fiberglass laminate. A full sized pattern is given in Figures 25 and 26. The ground planes on each side are connected together at several points with the feed-through capacitors, the BNC connectors and the mounting screws. From experience with an earlier broadband amplifier, it was learned that a good ground plane is extremely important because of the high currents and low impedance levels involved. The power supply impedance must be as low as possible.

The ac impedance of the supply should not be higher than 0.01 ohm at the lowest envelope frequency.

All dc connections are made on the back side of the board which is separated from the heat sink by 3/32 inches. The base bias resistors (R3, R10), and all by-pass capacitors, except the feed-throughs, are on the back side of the board in each end of the heat sink. Diode D2 is press fitted into the heat sink for temperature compensation of the quiescent collector currents of the 2N6368 transistors. Ceramic capacitors have been avoided, except for certain by-pass applications, because they have spurious resonances and, their capacitance values are voltage and temperature sensitive. Parallel capacitors are employed to increase the current carrying capability and to decrease the possibility of self resonances. The peak RF current in

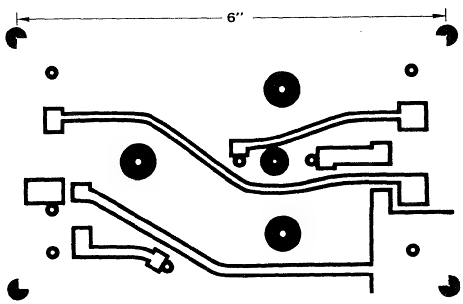



FIGURE 25 – Bottom PC Board Pattern

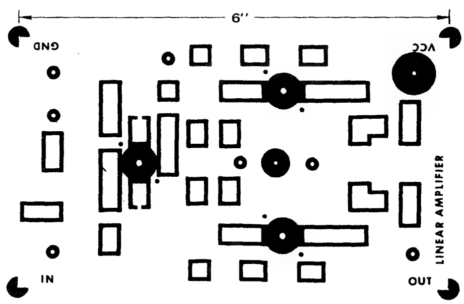



FIGURE 26 – Top Side of PC Board

TABLE III – HARMONIC SUPPRESSION versus FREQUENCY

| Harmonic | | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| Frequency | 3 MHz | -19 dB | -15 dB | -26 dB | -29 dB |
| | 6 MHz | -17 dB | -18 dB | -23 dB | -35 dB |
| | 12 MHz | -30 dB | -20 dB | -28 dB | -34 dB |
| | 30 MHz | -35 dB | -25 dB | -50 dB | -62 dB |

the output transformer primary is $\sqrt{\frac{80\ W}{6.25\ \Omega}} = 3.54A$. Half of this is supplied by each 2N6368. Thus, the collector isolation capacitors will have to handle 1.77A peak and 1.26A average currents. Even the lead sizes in most capacitors are insufficient for these current levels. In general, the low impedances involved in a 12.5 volt amplifier of this power level make the layout, construction and component selection somewhat critical compared to a higher voltage unit.

**CONSTRUCTION NOTES (28 V version)**

The 28 volt unit is less critical than the 12.5 V amplifier as far as the physical circuit lay-out is concerned. However, the same precautions should be taken in grounding the by-pass capacitors and the transformer high frequency-compensation capacitors. It is recommended that variable capacitors, such as the ARCO 460 line be used initially for the compensating capacitors. Then after establishing satisfactory operation of the unit, they can be changed to fixed value capacitors.

**IMPROVED PERFORMANCE**

Since the original work on these amplifiers, device improvements have been made. Both IMD and load mismatch ruggedness characteristics can be enhanced by substituting the MRF463 or MRF464 for the 2N5942 in the 28-Volt amplifier. The MRF460 is recommended for upgrading the 12-Volt amplifier using the 2N6368. Neither of these new devices require circuit modifications for optimum operation.

**REFERENCES**


1. Ruthroff: Some Broad Band Transformers, *IRE, Volume 47,* August, 1957.
2. Hilbers: Design of H. F. Wideband Power Transformers, *Philips Application Information #530.*
3. Pitzalis-Couse: Broadband Transformer Design for RF Transistor Amplifiers, *ECOM-2989,* July 1968.
4. Pappenfus; Bruene, Schoenike: Single Sideband Principles and Circuits, McGraw-Hill.
5. Granberg, H.; *Broadband Transformers and Power Combining Techniques for RF,* AN-749 Motorola Semiconductor Products Inc., June 1975.
6. Granberg, H.; *Get 300 Watts PEP Linear Across 2 to 30 MHz From This Push-Pull Amplifier,* EB-27 Motorola Semiconductor Products Inc., September 1974.
7. Granberg, H.; *A Complementary Symmetry Amplifier for 2 to 30 MHz SSB Driver Applications,* EB-32 Motorola Semiconductor Products Inc., February 1975.
8. Granberg, H.; *Measuring the Intermodulation Distortion of Linear Amplifiers,* EB-38 Motorola Semiconductor Products Inc., January 1975.

# 2-30 MHz, 50 Vdc

# CHAPTER 4

**MOTOROLA Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5941

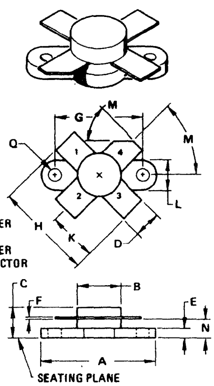
## The RF Line

**40 W (PEP)–30 MHz**
**RF POWER TRANSISTOR**
**NPN SILICON**

### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz, in single sideband mobile, marine and base station equipment.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 40 W (PEP)
  Minimum Gain = 13 dB
  Efficiency = 40%
  Intermodulation Distortion = -30 dB (Max)
- Isothermal-Resistor Design Results in Rugged Device




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

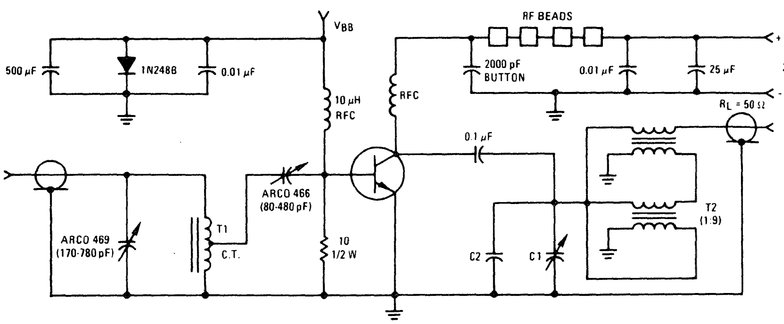
CASE 211-07

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 6.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above 25°C | $P_D$ | 80<br>0.457 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data

**FIGURE 1 – 30 MHz TEST CIRCUIT**




RFC: 20 TURNS #12 AWG ENAMELED WIRE CLOSE WOUND IN 2 LAYERS, 1/4" I.D.
T1: 20 TURNS #24 AWG WIRE WOUND ON MICRO-METALS T37-7 TOROID CORE CENTER TAPPED.
T2: 1:9 XFMR; 6 TURNS OF 2 TWISTED PAIRS OF #28 AWG ENAMELED WIRE. (8 CRESTS PER INCH) BIFILAR WOUND ON EACH OF 2 SEPARATE BALUN CORES. (Stackpole #57-1503, No. 14 Material) Interconnected as shown
RF BEADS: FERROXCUBE #56-590-65/38

$V_{BB}$ adjusted for $I_{CQ}$: 20 mAdc ($I_{CQ}$ = Quiescent Collector Current)

C1 – 80-480 pF, ARCO 466 or Equiv

C2 – 220 pF

4

*ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 0.25 Adc, $V_{CE}$ = 15 Vdc, f = 50 MHz) | $f_T$ | 50 | – | MHz |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 125 | pF |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 40 W (PEP), $I_C$ = 1.78 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 13 | – | dB |
| Intermodulation Distortion Ratio (Figure 1) ($P_{out}$ = 40 W (PEP), $I_C$ = 1.78 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -30 | dB |
| Collector Efficiency ($P_{out}$ = 40 W (PEP), $I_C$ = 1.78 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 40 | – | % |

* Indicates JEDEC Registered Data.

FIGURE 2
LINEAR OUTPUT POWER versus FREQUENCY

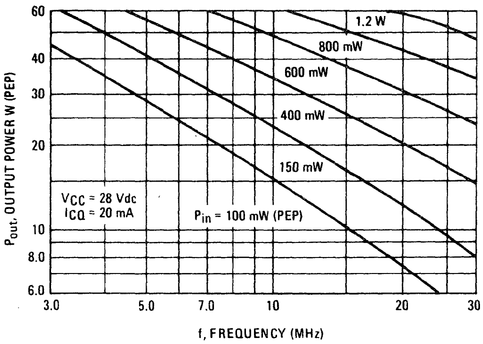



FIGURE 3
INTERMODULATION DISTORTION versus OUTPUT POWER
($f_1$ = 30 MHz, $f_2$ = 30.001 MHz)

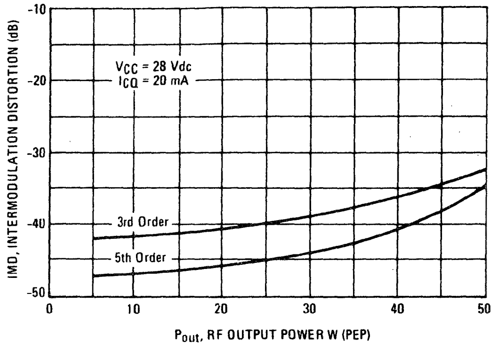



FIGURE 4
OUTPUT POWER versus INPUT POWER

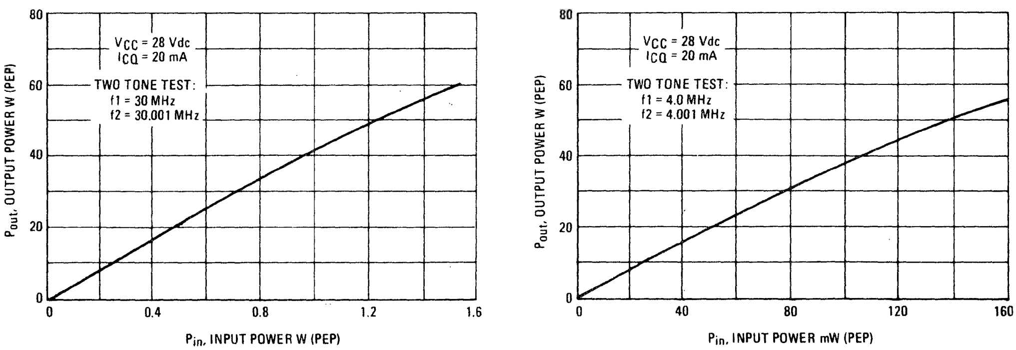



FIGURE 5
LINEAR OUTPUT POWER versus SUPPLY VOLTAGE
($f_1$ = 30 MHz, $f_2$ = 30.001 MHz)

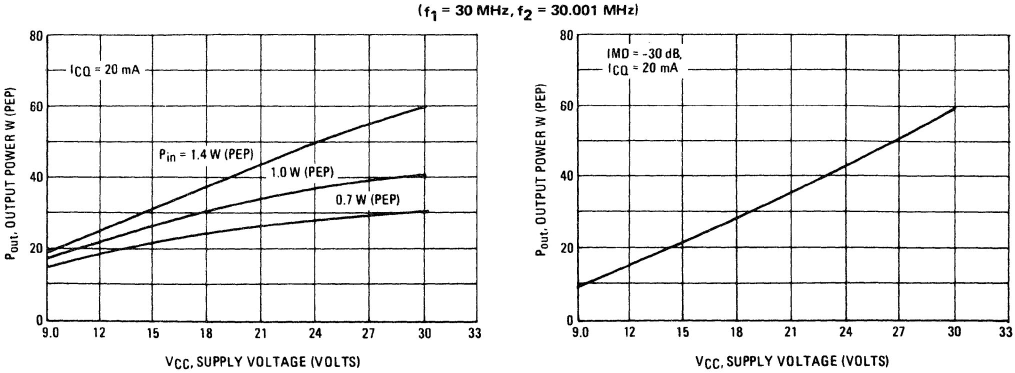


FIGURE 6
PARALLEL EQUIVALENT INPUT RESISTANCE
versus FREQUENCY

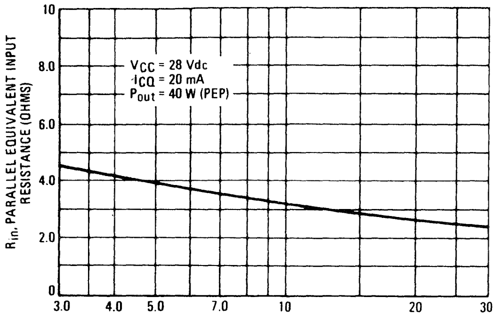



FIGURE 7
PARALLEL EQUIVALENT INPUT CAPACITANCE
versus FREQUENCY

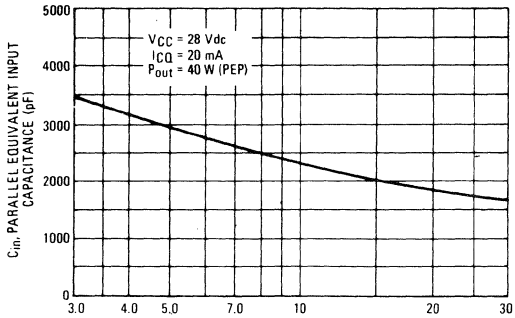



FIGURE 8
PARALLEL EQUIVALENT OUTPUT CAPACITANCE
versus FREQUENCY

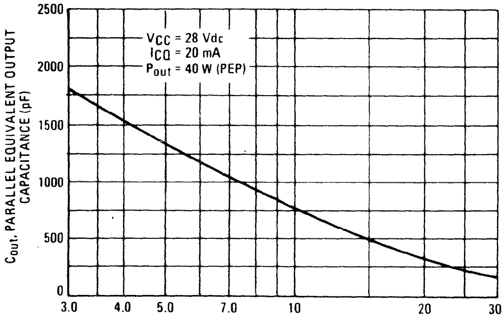



FIGURE 9
COLLECTOR CURRENT
versus BASE-EMITTER VOLTAGE

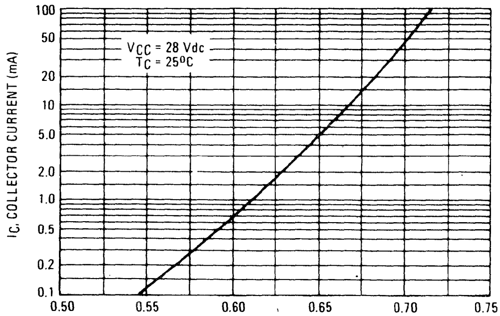
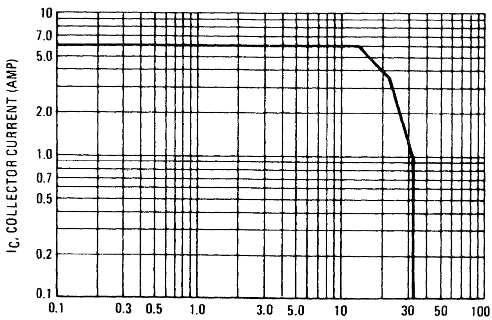



FIGURE 10
SAFE OPERATING AREA



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

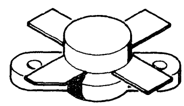
# MRF422

## The RF Line

150 W(PEP) – 30 MHz

**RF POWER TRANSISTOR**

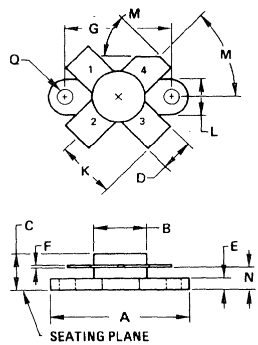
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 150 W(PEP)
  Minimum Gain = 10 dB
  Efficiency = 40%
- Intermodulation Distortion @ 150 W(PEP) –
  IMD = -30 dB (Min)
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.31 | 6.63 | 0.209 | 0.261 |
| D | 6.10 | 6.60 | 0.240 | 0.260 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 12.32 | – | 0.485 | – |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.30 | 4.06 | 0.130 | 0.160 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-08

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 40 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 85 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 20 | Adc |
| Withstanding Current – 10 s | – | 30 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 290<br>1.66 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

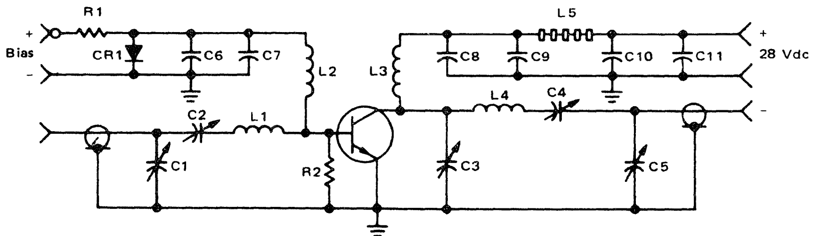
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.6 | $^oC/W$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 85 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 85 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 30 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | 350 | 420 | – | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 150 W(PEP), $I_{C(max)}$ = 6.7 Adc, $I_{CQ}$ = 150 mAdc, f = 30, 30.001 MHz) | $G_{PE}$ | 10 | 13 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 150 W(PEP), $I_{C(max)}$ = 6.7 Adc, $I_{CQ}$ = 150 mAdc, f = 30, 30.001 MHz) | $\eta$ | 40 | – | – | % |
| Intermodulation Distortion * ($V_{CE}$ = 28 Vdc, $P_{out}$ = 150 Watts(PEP), $I_C$ = 6.7 Adc, $I_{CQ}$ = 150 mAdc, f = 30, 30.001 MHz) | IMD | – | -33 | -30 | dB |
| Output Power ($V_{CE}$ = 28 Vdc, f = 30 MHz) | $P_{out}$ | 150 | – | – | Watts PEP |

*To Mil Std 1311 Version A, Test Method 2204, Two Tone, Reference each Tone.

**FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC**




C1,2,3,5 – 170-680 pF, ARCO 469
C4 – 80-480 pF, ARCO 466
C6,8,11 – ERIE 0.1 μF, 100 V
C7 – MALLORY 500 μF, 15 V Electrolytic
C9 – UNDERWOOD 1000 pF, 350 V
C10 – 100 μF, 15 V Electrolytic
R1 – 10 Ω, 25 Watt Wire Wound
R2 – 10 Ω, 1 Watt Carbon
CR1 – 1N4997

L1 – 3 Turns, #16 Wire, 5/16" I.D., 5/16" Long
L2 – 10 μH Molded Choke
L3 – 12 Turns, #16 Enamaled Wire, Close Wound, 1/4" Dia.
L4 – 5 Turns, 1/8" Copper Tubing
L5 – 10 Ferrite Beads – FERROXCUBE #56-590-65/3B

FIGURE 2 – OUTPUT POWER versus INPUT POWER

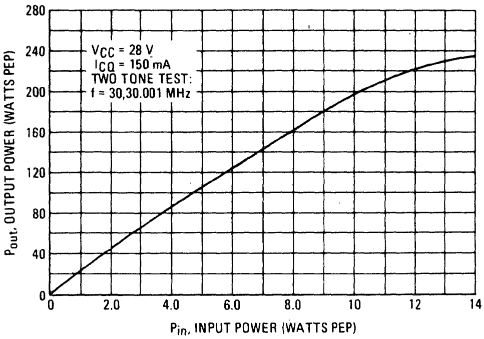



FIGURE 3 – POWER GAIN versus FREQUENCY

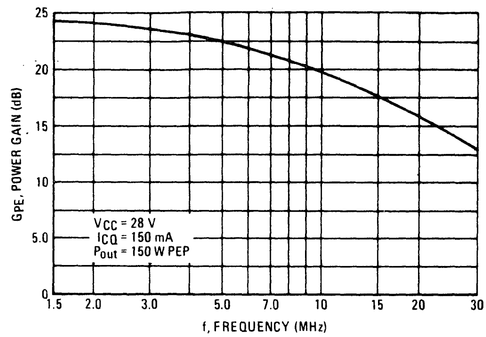



FIGURE 4 – LINEAR OUTPUT POWER versus SUPPLY VOLTAGE

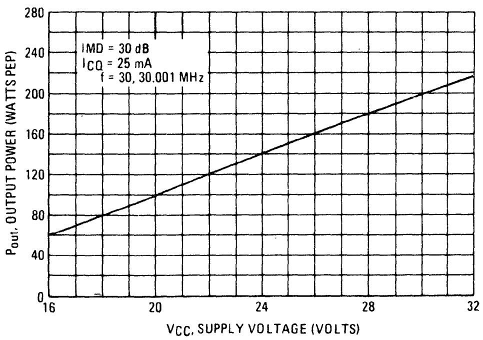



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER

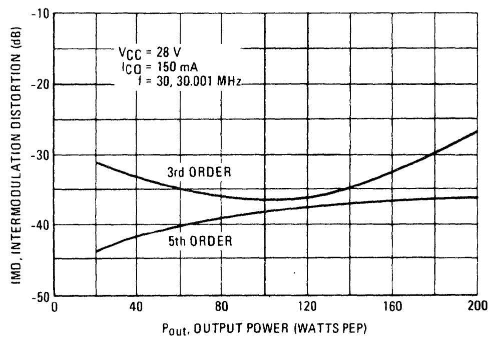



FIGURE 6 – DC SAFE OPERATING AREA

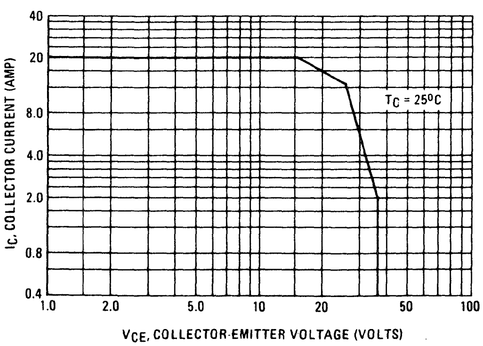
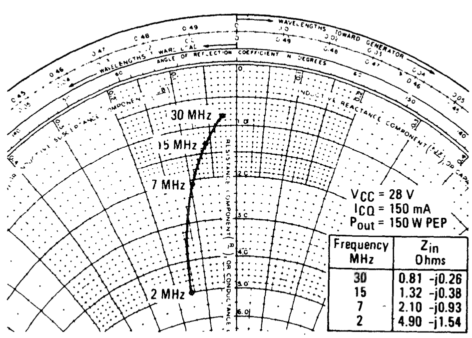



FIGURE 7 – SERIES INPUT IMPEDANCE




| Frequency MHz | Zin Ohms |
|---|---|
| 30 | 0.81 -j0.26 |
| 15 | 1.32 -j0.38 |
| 7 | 2.10 -j0.93 |
| 2 | 4.90 -j1.54 |

FIGURE 8 – OUTPUT RESISTANCE versus FREQUENCY

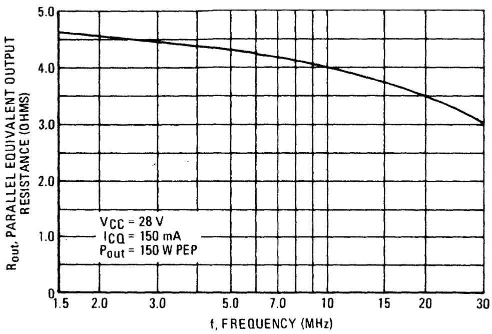
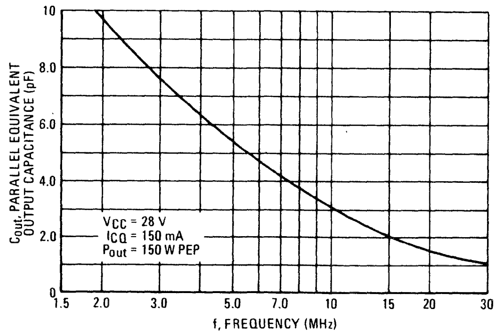



FIGURE 9 – OUTPUT CAPACITANCE versus FREQUENCY



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF427A

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

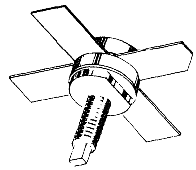
. . . designed primarily for high-voltage applications as a high-power linear amplifier from 2.0 to 30 MHz. Ideal for marine and base station equipment.

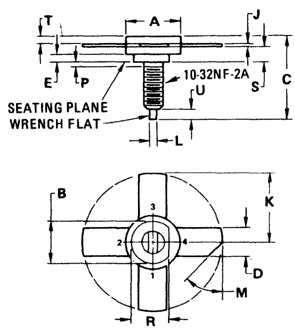
- Specified 50 Volt, 30 MHz Characteristics —
  Output Power = 25 W(PEP)
  Minimum Gain = 18 dB
- Intermodulation Distortion @ 25 W(PEP) —
  IMD = -34 dB (Min)
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR

25 W (PEP) — 30 MHz

**RF POWER TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-10

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 65 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 110 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 6.0 | Adc |
| Total Device Dissipation @ $T_C = 25^\circ C$<br>Derate above 25°C | $P_D$ | 80<br>0.457 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | −65° to +200° | °C |

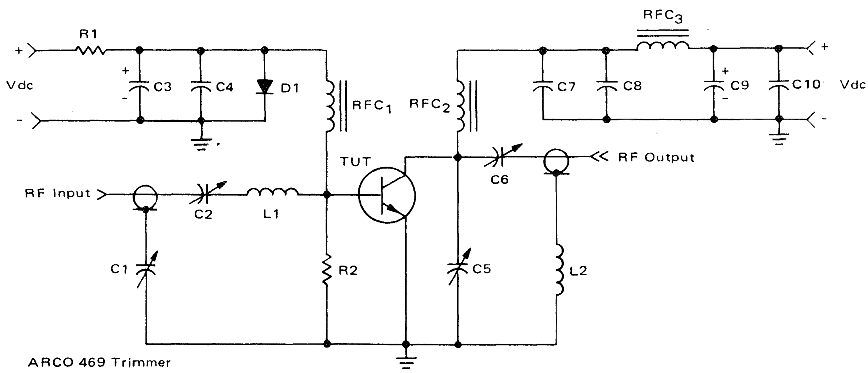
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.19 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 65 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 110 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 110 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 15 | – | 90 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 50 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 60 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 50 Vdc, $P_{out}$ = 25 W(PEP), f = 30 MHz) | $G_{pe}$ | 18 | 20 | – | dB |
| Intermodulation Distortion ($V_{CC}$ = 50 Vdc, $P_{out}$ = 25 W(PEP)) | IMD | -34 | -37 | – | dB |
| Electrical Ruggedness ($V_{CC}$ = 50 Vdc, $P_{out}$ = 25 W(PEP), f = 30 MHz, VSWR 30:1) All Phase Angles | | No Degradation in Output Power | | | |

FIGURE 1 — 30 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1,C2,C6 | ARCO 469 Trimmer | RFC1 | 1 μH Molded Choke |
| C3 | 500 μF, 3 Vdc Capacitor | RFC2 | 20 Turns, #20 AWG, Enameled Wire on 390 Ω, 1 Watt Resistor |
| C4,C7,C10 | 0.1 μF ERIE REDCAP | RFC3 | VK 200-4B FERROXCUBE Choke |
| C5 | ARCO 463 Trimmer | | |
| C8 | 1000 pF, UNELCO Capacitor | | |
| C9 | 47 μF, 50 Vdc Capacitor | | |
| R1 | 20 Ω, 5 Watt Resistor | | |
| R2 | 10 Ω, ½ Watt Resistor | | |
| L1 | 0.15 μH Inductor | | |
| L2 | 0.3 μH Inductor | | |
| D1 | 1N4997 | | |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

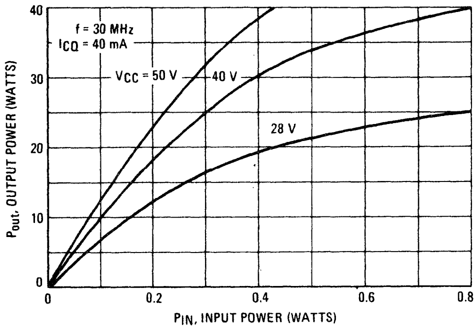



FIGURE 3 – POWER GAIN versus FREQUENCY.

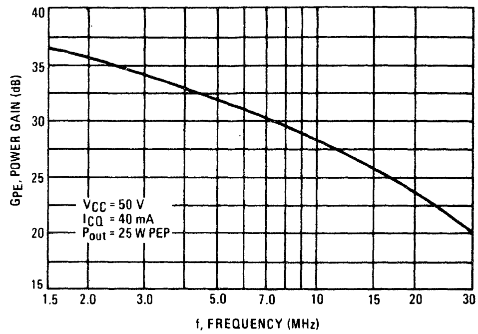



FIGURE 4 – INTERMODULATION DISTORTION versus OUTPUT POWER
$V_{CC}$ = 50 Vdc

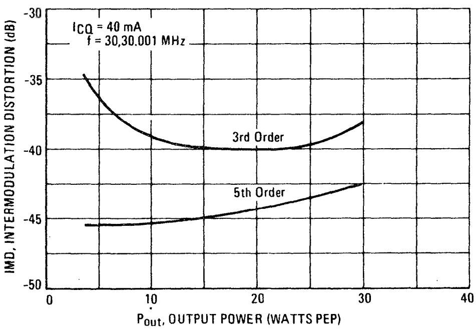



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER
$V_{CC}$ = 40 Vdc

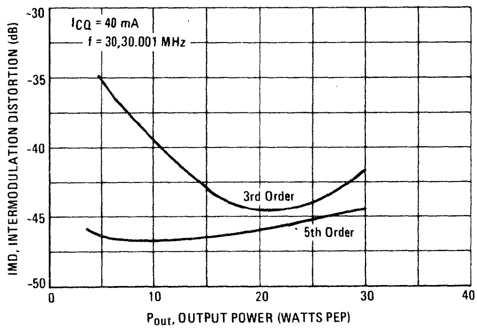



FIGURE 6 – OUTPUT RESISTANCE versus FREQUENCY

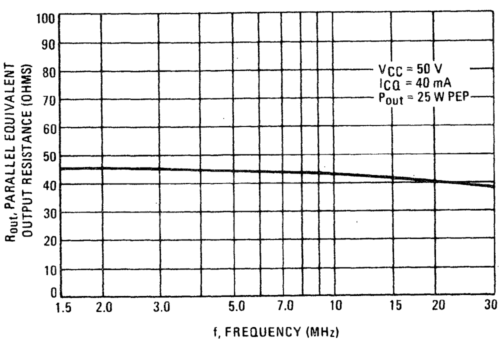



FIGURE 7 – OUTPUT CAPACITANCE versus FREQUENCY

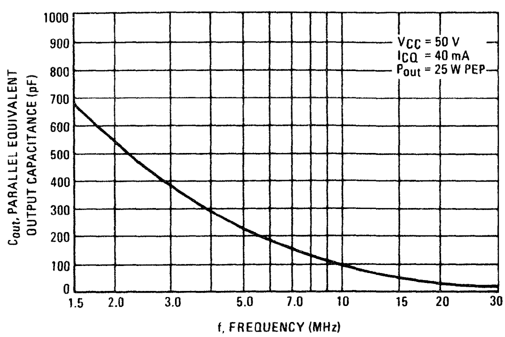


**FIGURE 8 — OUTPUT POWER versus SUPPLY VOLTAGE**

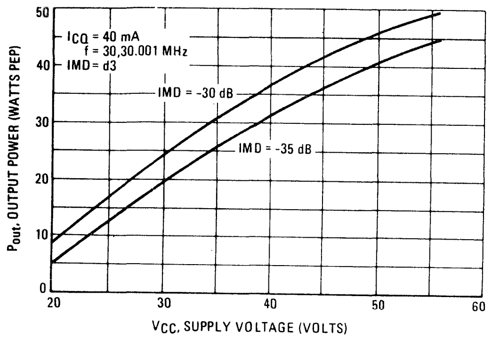



**FIGURE 9 — DC SAFE OPERATING AREA**

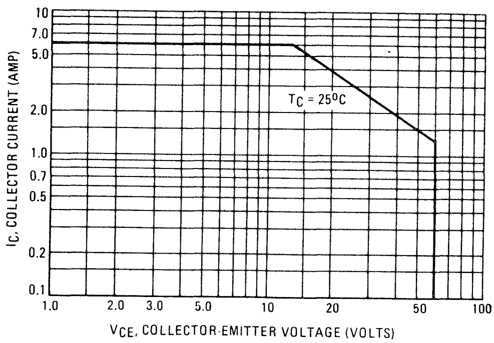
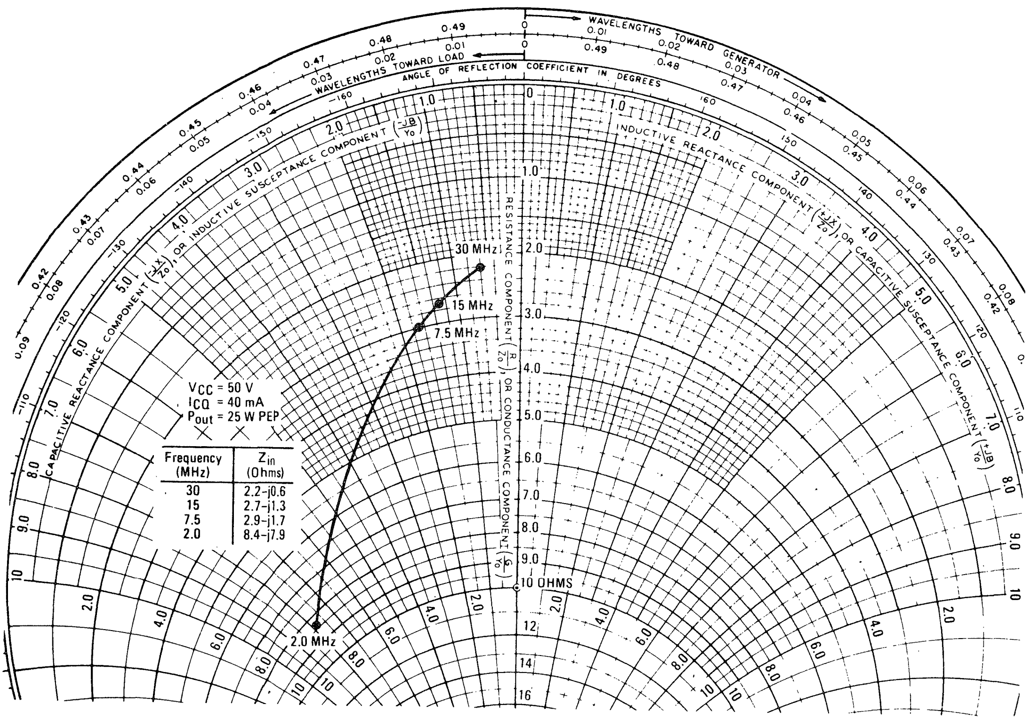



**FIGURE 10 — SERIES EQUIVALENT IMPEDANCE**




| Frequency (MHz) | $Z_{in}$ (Ohms) |
|---|---|
| 30 | 2.2-j0.6 |
| 15 | 2.7-j1.3 |
| 7.5 | 2.9-j1.7 |
| 2.0 | 8.4-j7.9 |

MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF428A

## The RF Line

150 W (PEP) – 30 MHz

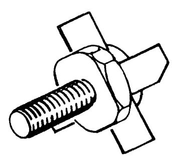
RF POWER
TRANSISTOR

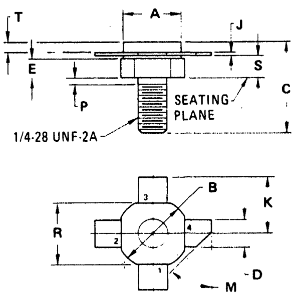
NPN SILICON

### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for high-voltage applications as a high-power linear amplifier from 2.0 to 30 MHz. Ideal for marine and base station equipment.

- Specified 50 Volt, 30 MHz Characteristics –
  Output Power = 150 W(PEP)
  Minimum Gain = 13 dB
  Efficiency = 45%
- Intermodulation Distortion @ 150 W (PEP) –
  IMD = -30 dB (Max)
- 100% Tested for Load Mismatch at all Phase Angles with
  30:1 VSWR






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 15.62 | 16.13 | 0.615 | 0.635 |
| C | 18.92 | 21.46 | 0.745 | 0.845 |
| D | 6.10 | 6.60 | 0.240 | 0.260 |
| E | 4.06 | 4.57 | 0.160 | 0.180 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.32 | 13.08 | 0.485 | 0.515 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 13.72 | 14.22 | 0.540 | 0.560 |
| S | 4.83 | 5.33 | 0.190 | 0.210 |
| T | 2.03 | 2.54 | 0.080 | 0.100 |

CASE 307-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 55 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 110 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 20 | Adc |
| Withstand Current – 10 s | – | 30 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 320<br>1.83 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

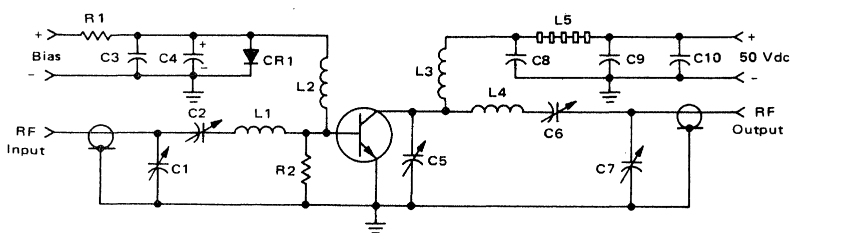
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.5 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 55 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 110 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 110 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 30 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 50 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 200 | 250 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Gain ($V_{CC}$ = 50 Vdc, $P_{out}$ = 150 W (PEP) $I_C$(max) = 3.32 Adc, f = 30 MHz) | $G_{PE}$ | 13 | 15 | – | dB |
| Output Power ($V_{CE}$ = 50 Vdc, f = 30 MHz) | $P_{out}$ | 150 | – | – | W PEP |
| Collector Efficiency ($V_{CC}$ = 50 Vdc, $P_{out}$ = 150 W (PEP), $I_C$(max) = 3.32 Adc, f = 30 MHz) | $\eta$ | 45 | – | – | % |
| Intermodulation Distortion (1) ($V_{CE}$ = 50 Vdc, $P_{out}$ = 150 W (PEP), $I_C$ = 3.32 Adc) | IMD | – | -33 | -30 | dB |
| Electrical Ruggedness ($V_{CC}$ = 50 Vdc, $P_{out}$ = 150 W (PEP), $I_C$(max) = 3.32 Adc, f = 30 MHz) VSWR 30:1 at all Phase Angles | No Degradation in Output Power | | | | |

(1) To Mil Std 1311 Version A, Test Method 2204B, Two Tone, Reference Each Tone.

**FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1,C2,C7 | 170-780 pF, ARCO 469 | R2 | 10 Ω, 1 Watt |
| C3,C8,C9 | 0.1 μF, 100 V ERIE | CR1 | 1N4997 |
| C4 | 500 μF @ 6 V | L1 | 3 Turns, #16 Wire, 5/16" I.D., 5/16" Long |
| C5 | 9.0-180 pF, ARCO 463 | L2 | 10 μH Molded Choke |
| C6 | 80-480 pF, ARCO 466 | L3 | 12 Turns, #16 Enamaled Wire Closewound, 1/4" I.D. |
| C10 | 30 μF, 100 V | L4 | 5 Turns, 1/8" Copper Tubing, 9/16" I.D., 3/4" Long |
| R1 | 10 Ω, 10 Watt | L5 | 10 Ferrite Beads – FERROXCUBE #56-590-65/3B |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

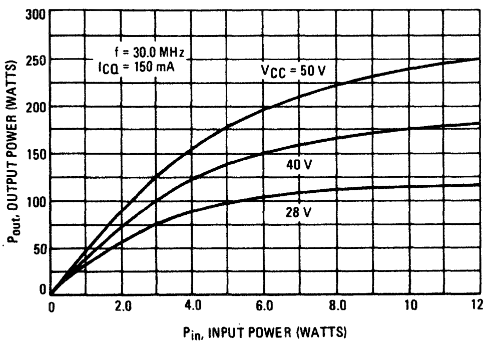



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

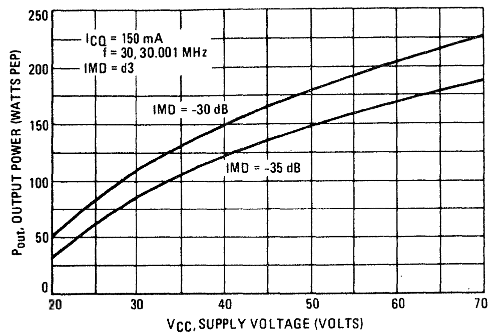



FIGURE 4 – POWER GAIN versus FREQUENCY

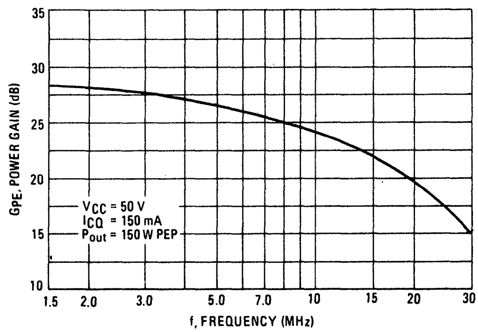
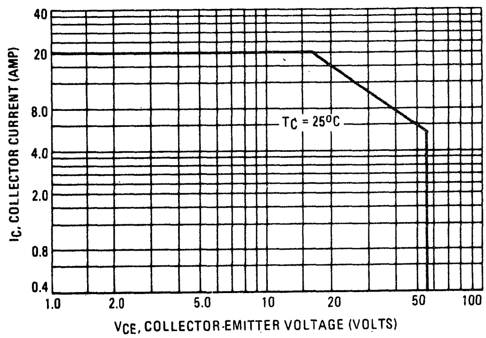



FIGURE 5 – DC SAFE OPERATING AREA




## INTERMODULATION DISTORTION versus OUTPUT POWER

FIGURE 6 – $V_{CC}$ = 40 Vdc

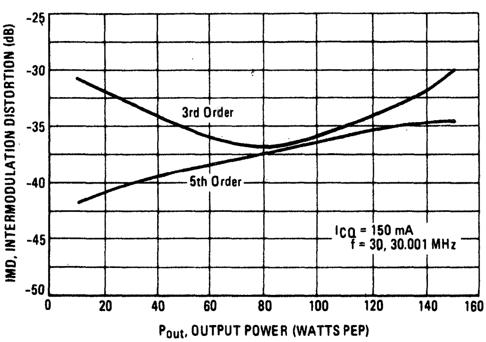



FIGURE 7 – $V_{CC}$ = 50 Vdc

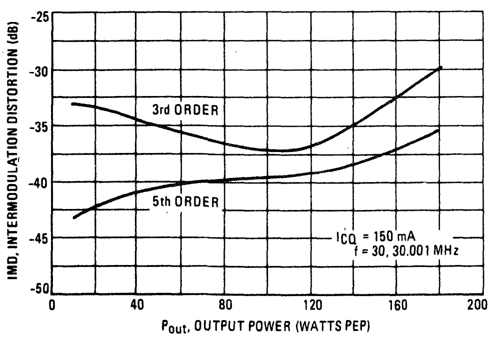


FIGURE 8 – OUTPUT CAPACITANCE versus FREQUENCY

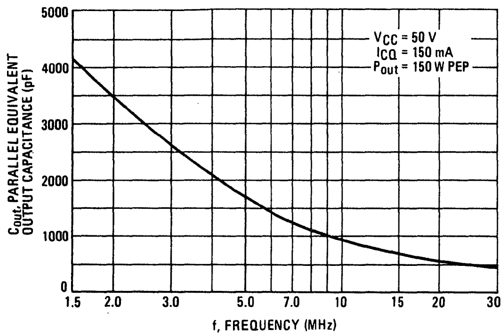



FIGURE 9 – OUTPUT RESISTANCE versus FREQUENCY

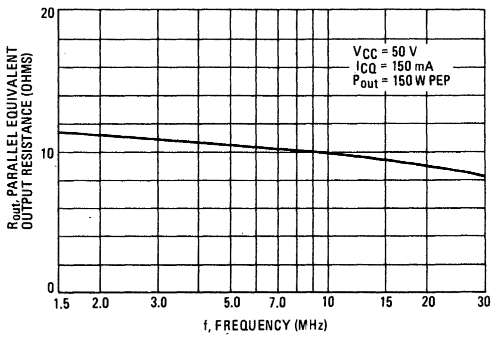
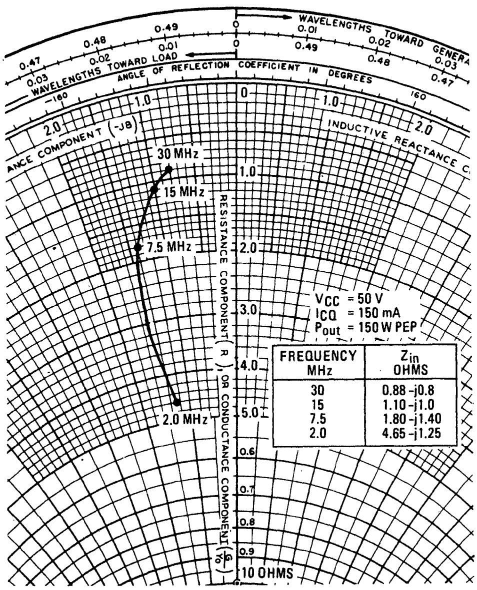



FIGURE 10 – SERIES EQUIVALENT IMPEDANCE



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF463

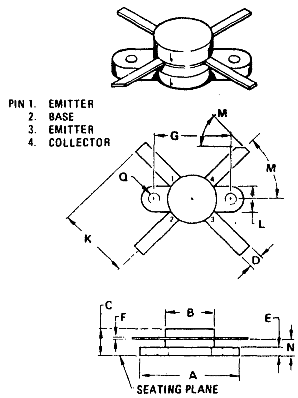
## The RF Line

**80 W (PEP) — 30 MHz**
**RF POWER TRANSISTOR**
**NPN SILICON**

## NPN SILICON RF POWER TRANSISTORS

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz, in single sideband mobile, marine and base station equipment.

- Specified 28 Volt, 30 MHz Characteristics —
  Output Power = 80 W (PEP)
  Minimum Gain = 15 dB
  Efficiency = 40%
  Intermodulation Distortion = −32 dB (Max)
- Motorola Improved Single Die Replacement for 2N5942




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 11.81 | 12.95 | 0.465 | 0.510 |
| C | 5.82 | 6.98 | 0.229 | 0.275 |
| D | 2.16 | 3.94 | 0.085 | 0.155 |
| E | 2.13 | 2.79 | 0.084 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 17.78 | – | 0.700 | – |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.66 | 4.52 | 0.144 | 0.178 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |

CASE 211-10

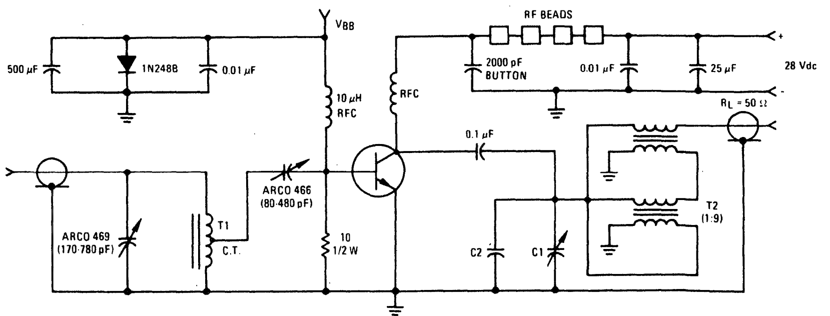
### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 10 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 250<br>1.4 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | −65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.7 | °C/W |

**FIGURE 1—30 MHz TEST CIRCUIT**




RFC: 20 TURNS #12 AWG ENAMELED WIRE CLOSE WOUND IN 2 LAYERS, 1/4" I.D.
T1: 20 TURNS #24 AWG WIRE WOUND ON MICRO-METALS T37-7 TOROID CORE CENTER TAPPED.
T2: 1:9 XFMR; 6 TURNS OF 2 TWISTED PAIRS OF #28 AWG ENAMELED WIRE. (8 CRESTS PER INCH) BIFILAR WOUND ON EACH OF 2 SEPARATE BALUN CORES. (Stackpole #57-1503, No. 14 Material) Interconnected as shown
RF BEADS: FERROXCUBE #56-590-65/3B

$V_{BB}$ adjusted for $I_{CQ}$: 40 mAdc ($I_{CQ}$ = Quiescent Collector Current)

C1 – 170-180 pF ARCO 469 or Equiv.

C2 – 330 pF

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 200 | pF |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 15 | – | dB |
| Intermodulation Distortion Ratio (Figure 1) ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -32 | dB |
| Collector Efficiency ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 40 | – | % |

## MATCHING PROCEDURE

In the push-pull circuit configuration two device parameters are critical for optimum circuit performance. These parameters are $V_{BE(on)}$ and $h_{FE}$. Both parameters can be guaranteed by measuring $I_{CQ}$ of the devices and selecting pairs with a $\Delta I_{CQ} \leqslant$ 10 mAdc.

Actual $I_{CQ}$ matching is performed in the MRF463 test circuit with a $V_{CE}$ equal to 28 Volts. The base bias supply is adjusted to set $I_{CQ}$ equal to 40 mAdc using a reference standard MRF463. The $I_{CQ}$ of all production MRF463 transistors is measured using this base bias supply setting. The production MRF463's are tested and categorized in ranges of 10 mAdc. Finally, the devices are stocked as pairs with a guaranteed $\Delta I_{CQ} \leqslant$ 10 mAdc.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

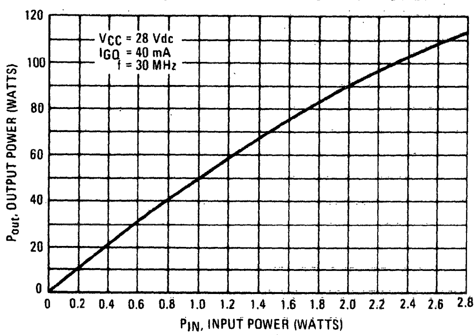



FIGURE 3 – POWER GAIN versus FREQUENCY

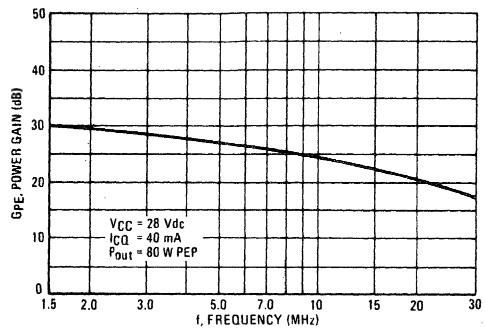



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

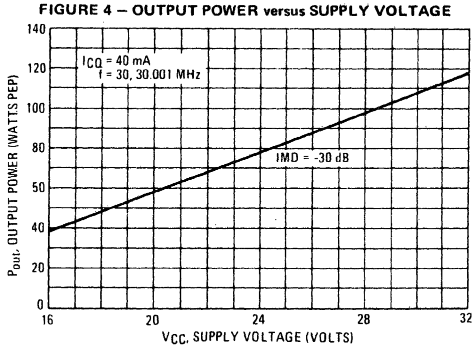



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER

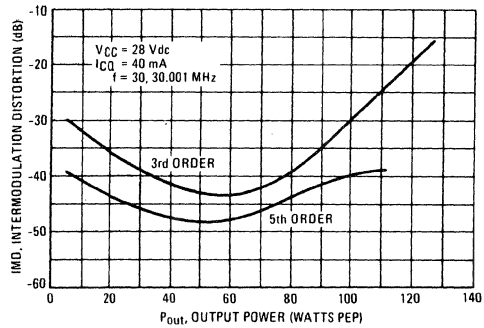



FIGURE 6 – OUTPUT CAPACITANCE versus FREQUENCY

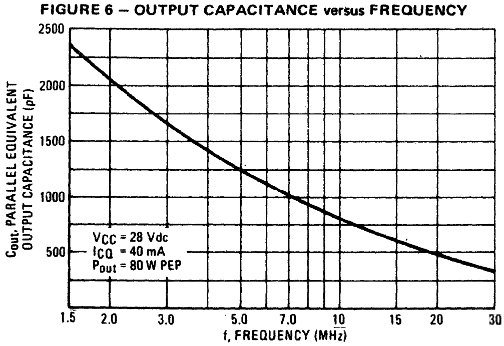



FIGURE 7 – OUTPUT RESISTANCE versus FREQUENCY

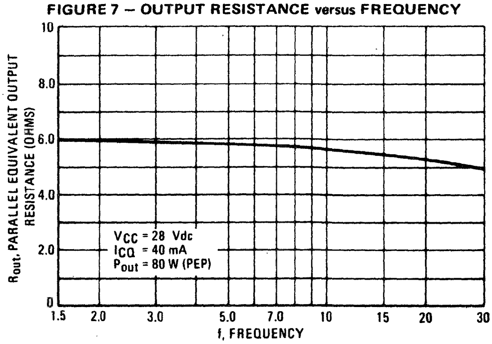


FIGURE 8 – DC SAFE OPERATING AREA

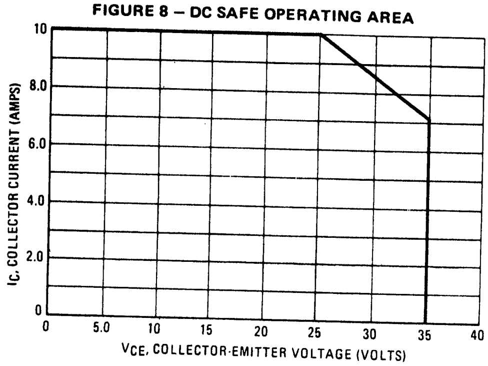
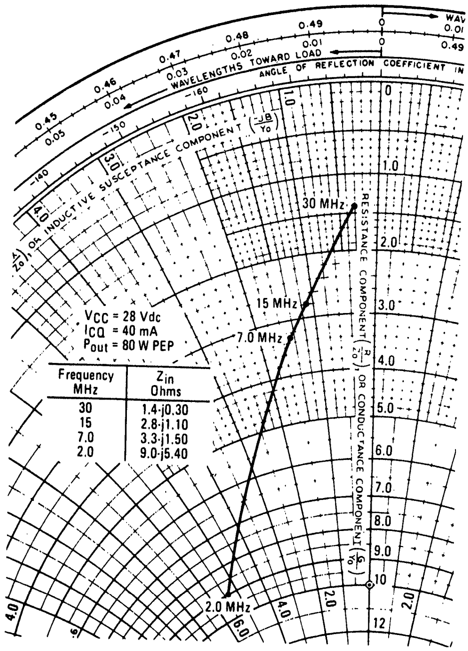



FIGURE 9 – SERIES INPUT IMPEDANCE




| Frequency MHz | Zin Ohms |
|---|---|
| 30 | 1.4-j0.30 |
| 15 | 2.8-j1.10 |
| 7.0 | 3.3-j1.50 |
| 2.0 | 9.0-j5.40 |

MOTOROLA Semiconductor Products Inc.

MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF464
# MRF464A

## The RF Line

80 W (PEP) – 30 MHz

RF POWER
TRANSISTOR
NPN SILICON

## NPN SILICON RF POWER TRANSISTORS

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz, in single sideband mobile, marine and base station equipment.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 80 W (PEP)
  Minimum Gain = 15 dB
  Efficiency = 40%
  Intermodulation Distortion = –32 dB (Max)

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 10 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 250<br>1.4 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

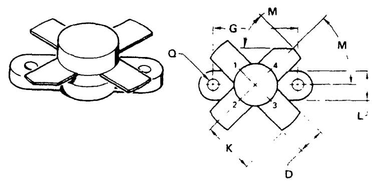
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.7 | °C/W |
| Stud Torque (1) | – | 8.5 | In. Lb |

(1) Case 145A For Repeated Assembly Use 11 In. Lb.

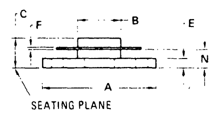
### MATCHING PROCEDURE

In the push-pull circuit configuration it is preferred that the transistors are used as matched pairs to obtain optimum performance.

The matching procedure used by Motorola consists of measuring $h_{FE}$ at the data sheet conditions and color coding the device to predetermined $h_{FE}$ ranges within the normal $h_{FE}$ limits. A color dot is added to the marking on top of the cap. Any two devices with the same color dot can be paired together to form a matched set of units.



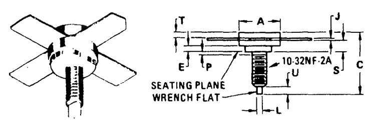

STYLE 1
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR



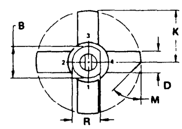

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 11.81 | 12.95 | 0.465 | 0.510 |
| C | 5.82 | 6.98 | 0.229 | 0.275 |
| D | 5.46 | 5.97 | 0.216 | 0.235 |
| E | 2.13 | 2.79 | 0.084 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 11.05 | – | 0.435 | – |
| L | 6.22 | 6.48 | 0.246 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.66 | 4.52 | 0.144 | 0.178 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |

CASE 211-11

MRF464




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

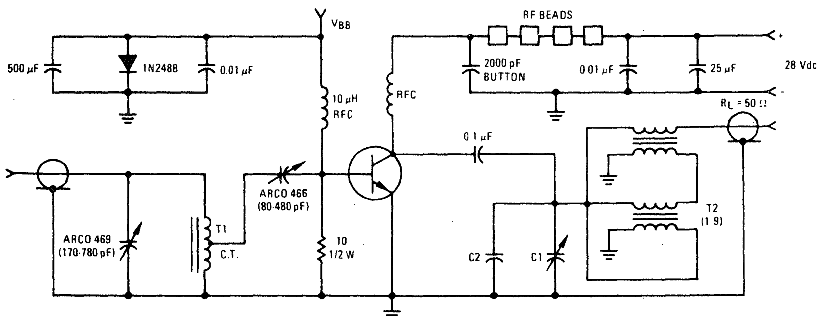
145A-10

MRF464A

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 200 | pF |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $G_{PE}$ | 15 | – | dB |
| Intermodulation Distortion Ratio (Figure 1) ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | IMD | – | -32 | dB |
| Collector Efficiency ($P_{out}$ = 80 W (PEP), $I_C$ = 3.6 Adc (Max), $V_{CC}$ = 28 Vdc, $f_1$ = 30 MHz, $f_2$ = 30.001 MHz) | $\eta$ | 40 | – | % |

**FIGURE 1—30 MHz TEST CIRCUIT**




RFC: 20 TURNS #12 AWG ENAMELED WIRE CLOSE WOUND IN 2 LAYERS, 1/4" I.D.
T1: 20 TURNS #24 AWG WIRE WOUND ON MICRO-METALS T37-7 TOROID CORE CENTER TAPPED.
T2: 1:9 XFMR; 6 TURNS OF 2 TWISTED PAIRS OF #28 AWG ENAMELED WIRE. (8 CRESTS PER INCH) BIFILAR WOUND ON EACH OF 2 SEPARATE BALUN CORES. (Stackpole #57-1503, No. 14 Material) Interconnected as shown
RF BEADS: FERROXCUBE #56-590-65/3B

$V_{BB}$ adjusted for $I_{CQ}$ 40 mAdc ($I_{CQ}$ = Quiescent Collector Current)

C1 – 170-180 pF ARCO 469 or Equiv.

C2 – 330 pF

FIGURE 2 – OUTPUT POWER versus INPUT POWER

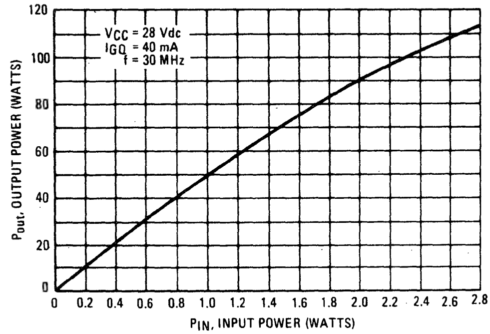



FIGURE 3 – POWER GAIN versus FREQUENCY

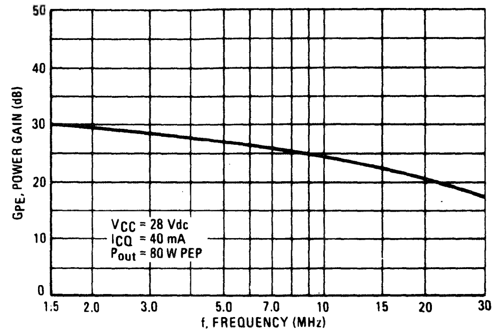



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

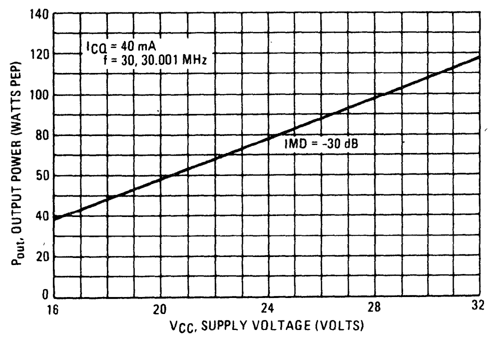



FIGURE 5 – INTERMODULATION DISTORTION versus OUTPUT POWER

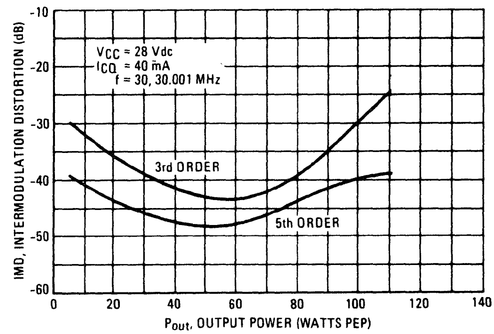



FIGURE 6 – OUTPUT CAPACITANCE versus FREQUENCY

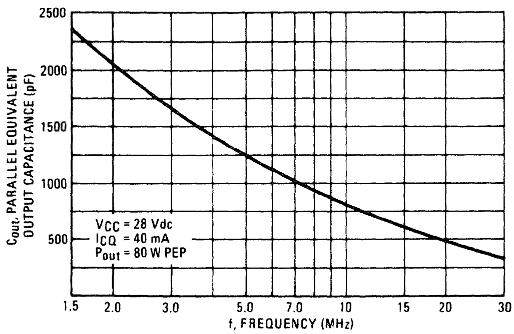



FIGURE 7 – OUTPUT RESISTANCE versus FREQUENCY

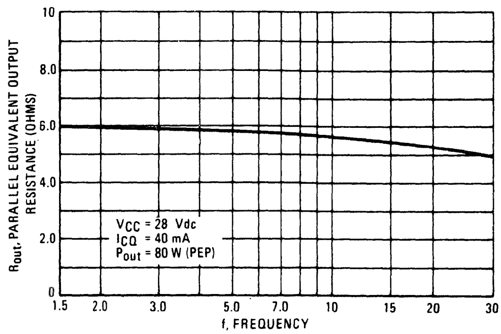


FIGURE 8 – DC SAFE OPERATING AREA

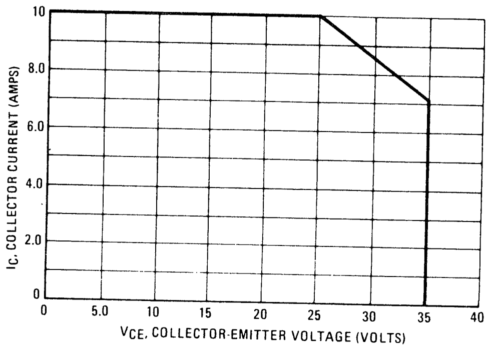
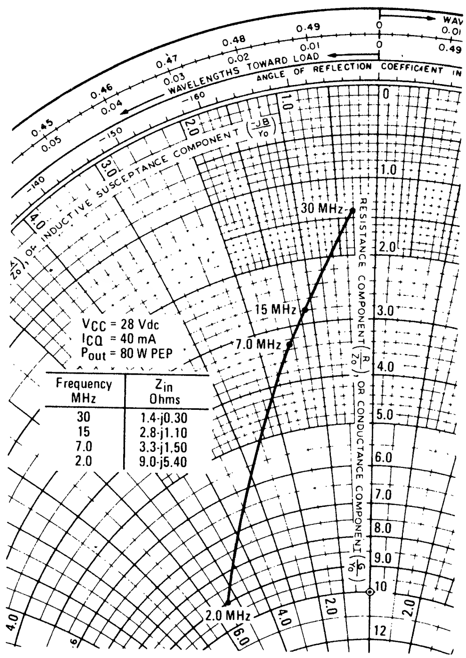


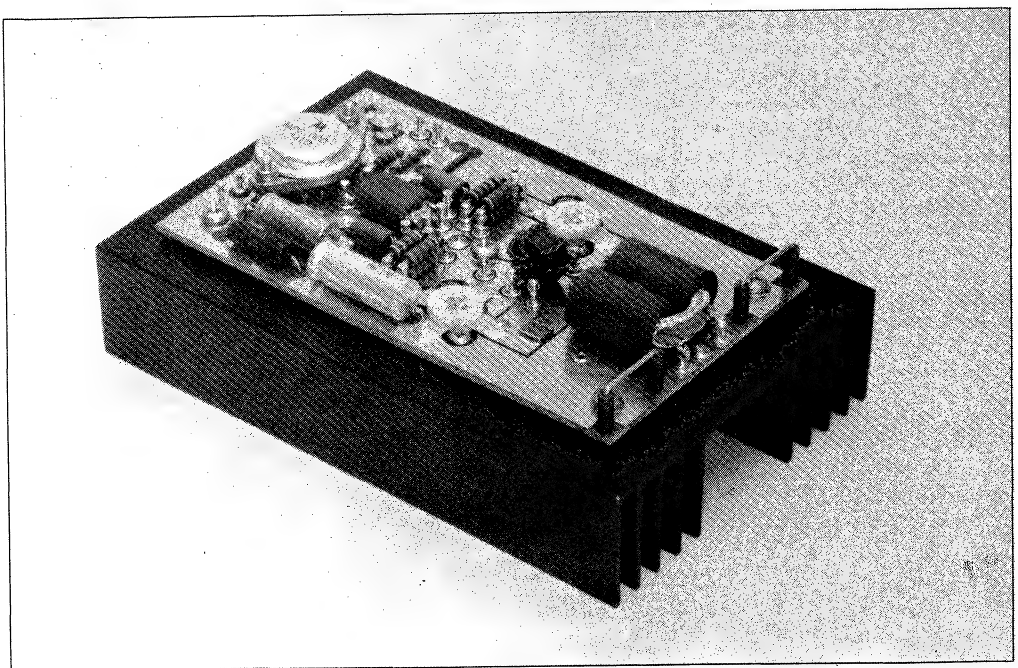

FIGURE 9 – SERIES INPUT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms |
|---|---|
| 30 | 1.4-j0.30 |
| 15 | 2.8-j1.10 |
| 7.0 | 3.3-j1.50 |
| 2.0 | 9.0-j5.40 |

# Get 300 Watts PEP Linear Across 2 To 30 MHz From This Push-Pull Amplifier

*Prepared by:*
**Helge Granberg**



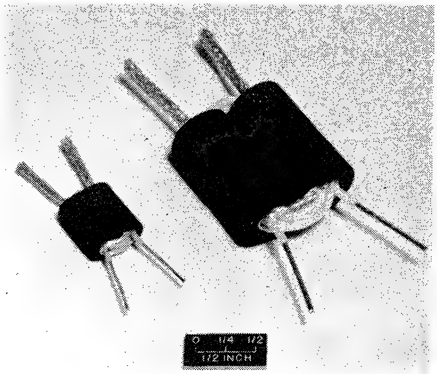
(The heat sink shown with amplifier is sufficient only for short test periods under forced air cooling.)

This bulletin supplies sufficient information to build a push-pull linear amplifier for 300 watts of PEP or CW output power across the 2- to 30-MHz band. One of Motorola's new high-power transistors developed for single-sideband, MRF422, is used in this application.

Like all transistors in its family of devices, MRF422 combines single-chip construction that is advancing the state-of-the-art, and improved packaging to accomodate the low collector efficiencies encountered in class B operation. Rated maximum output power is 150 watts CW or PEP with intermodulation distortion spec'd at –30 dB maximum, –33 dB typical. Although not recommended, a saturated power level of 240- to 250-W is achievable. Maximum allowable dissipation is 300 W at 25°C.

The amplifier's output power is limited by an output matching transformer with a 3:1 turns ratio, corresponding to a 9:1 impedance ratio. The measured impedance ratio, however, is 10:1, approaching the optimum for a 300-watt power level from a 28-volt supply.

Because of its excellent load and line voltage regulating capabilities, an integrated circuit bias regulator is used in the amplifier. Load regulation typically measures less than 2% at current levels up to 0.5 A. The MPC1000 regulator is rated for 10 A, and a dissipation of 100 W, when properly heatsunk. In this application, however, because the average base current of the rf power devices is less than 500 mA, no heatsink is necessary. With the component values shown, the bias is adjustable from 0.4 to 0.9 volts.




Transformer Construction

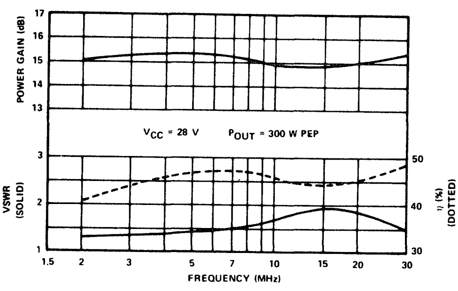
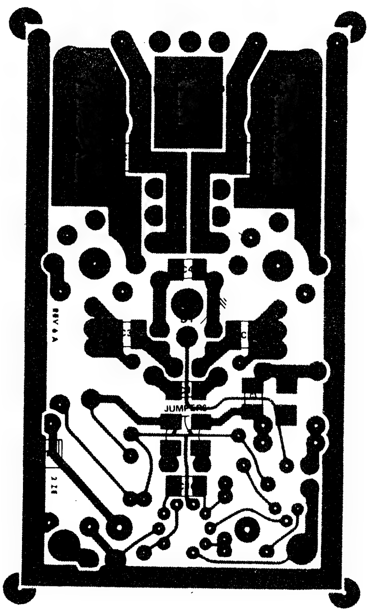
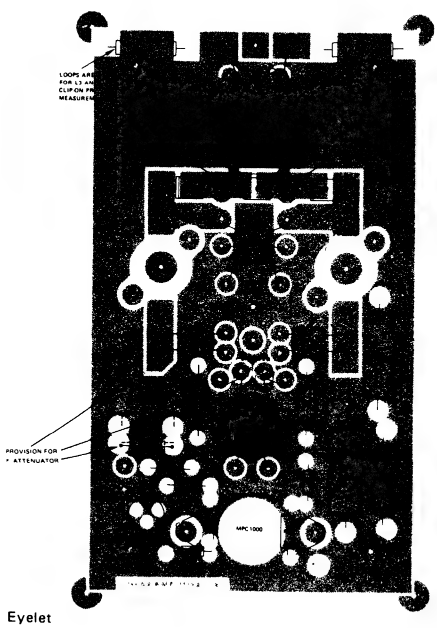



**Figure 1.** Collector Efficiency, Power Gain and VSWR vs Frequency

Gain flatness over the band is achieved using base input networks $R_1C_2$ and $R_2C_3$ and negative feedback through $R_3$ and $R_4$. The networks represent a series reactance of 0.69 ohms at 30 MHz rising to 1.48 ohms at 2 MHz. A single-turn winding in the collector choke provides a low-impedance negative feedback source, thus $R_3$ and $R_4$ determine the amount. The reactance of $C_4$ reduces feedback at high frequencies with the result that feedback increases an average of 4 dB per octave at decreasing frequency.

The effective base-to-base impedance, increased by the RC networks is about 5 ohms at midband. As a result of this and the 9:1 impedance ratio in the input transformer T1, the input VSWR is limited to 1:1.9 or less across the band. Transformer T2, in addition to providing a source for the feedback and carrying the dc collector current, acts as the rf center tap of the output transformer. To construct T2, wind 5 turns of 2 twisted pairs of AWG No. 22 enameled wire on a Stackpole 57-9322 toroid (Indiana General F627-8Q1).



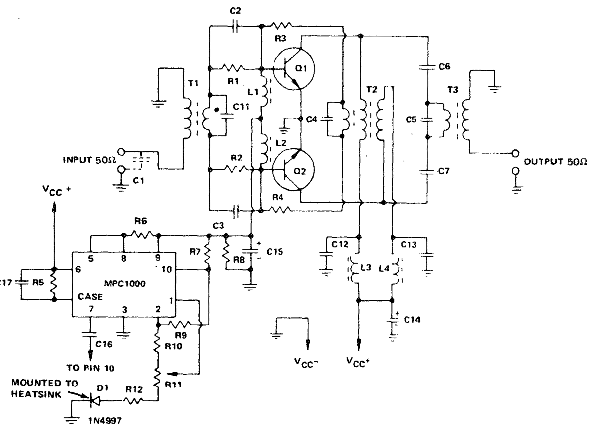




x — Feedthrough Eyelet

● — Component Mounting Hole

◎ — Board Standoff

⊗ — Terminal Pin




C1 - 100 pF
C2, C3 - 5600 pF
C4, C5 - 680 pF
C6, C7 - .10 μF
C11 - 470 pF
C12, C13 - .33 μF
C14 - 10 μF - 50 V electrolytic
C15 - 500 μF - 3 V electrolytic
C16 - 1000 pF
C17 - .1 μF

R1, R2 - 2 X 3.3Ω, 1/2-W in parallel
R3, R4 - 2 X 3.9Ω, 1/2-W in parallel
R5 - 47Ω, 5 W
R6 - 1.0Ω, 1/2 W
R7 - 1.0 k, 1/4 W
R8 - 100Ω, 1/4 W
R9 - 18 k, 1/4 W
R10 - 8.2 k, 1/4 W
R11 - 1.0 k Trimpot
R12 - 180Ω, 1/4 W
L1, L2 - Ferroxcube VK200 20/4B
L3, L4 — 6 ferrite beads each, Ferroxcube 56590 65/3B

Q1, Q2 - MRF422
T1, T2, T3 - See text

All capacitors except electrolytics are chips -
Union Carbide type 1813 and 1225, or Varadyne size 18 or 14, or equivalent

300-Watt Linear Amplifier Schematic Diagram

A Stackpole dual balun ferrite core 57-1845-24B is used for T1. The secondary is made of 1/8" copper braid, through which three turns of the primary winding (No. 22 Teflon® insulated hook-up wire) are threaded. The construction of T3 is similar to that of T1. It employs two Stackpole 57-3238* ferrite sleeves which are cemented together for easier construction. The primary is made of 1/4" copper braid, through which three turns of No. 16 Teflon® insulated wire are threaded for the secondary. The bandwidth characteristics of these transformers do not equal those of the transmission line type, but they're much easier to duplicate.

The measured performance of the amplifier is shown in figures 1, 2, and 3 and harmonic rejection data in table I.

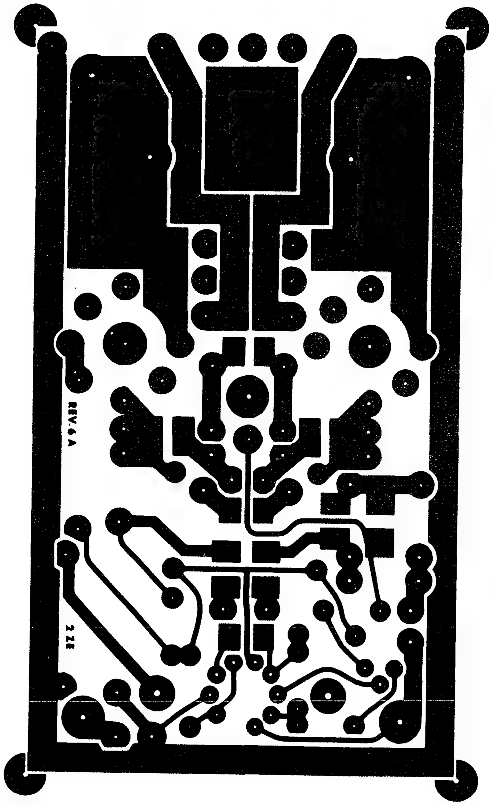
A recommended replacement for the MCP1000 is an MC1723CG and 2N5990 along with the PC board layout shown in AN-758. $D_2$ can be omitted and the value of $R_7$ should be reduced to 39-47 ohms for 28 volt operation. Other component values are as described in this bulletin.

Table I. Output harmonic contents, measured at 300-W CW (all test data taken using a tuned output, narrow band signal source).

| | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|
| f (MHz) | (dB below the carrier) | | | |
| 30.0 | -38 | -25 | -34 | -48 |
| 20.0 | -33 | -13 | -43 | -45 |
| 15.0 | -50 | -10 | -51 | -47 |
| 7.50 | -40 | -30 | -55 | -47 |
| 4.0 | -37 | -22 | -55 | -37 |
| 2.0 | -36 | -18 | -45 | -37 |

*A similar product is available from Fair-Rite Products Corp., Wallkill, N.Y. 12589

®Registered trademark of DuPont



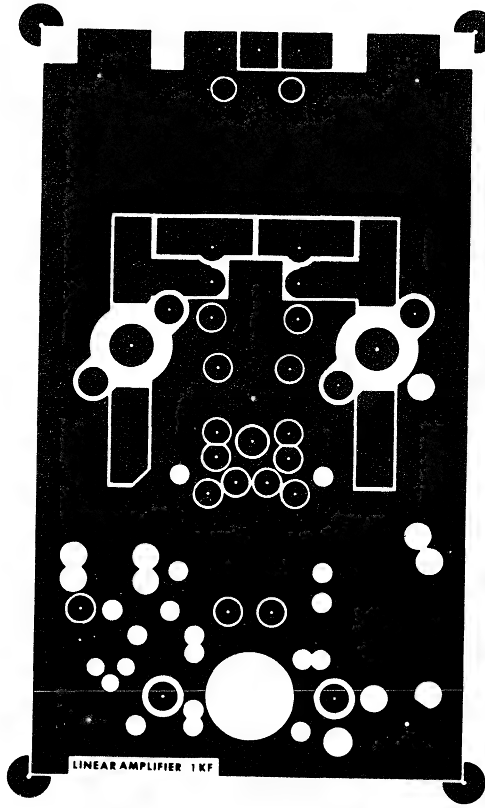




**Figure 2.** IMD vs Frequency

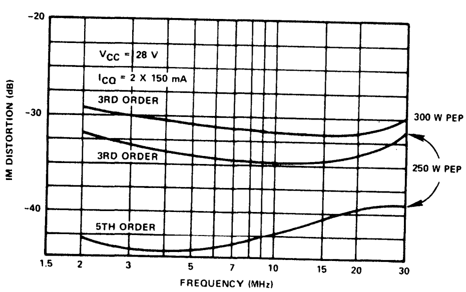
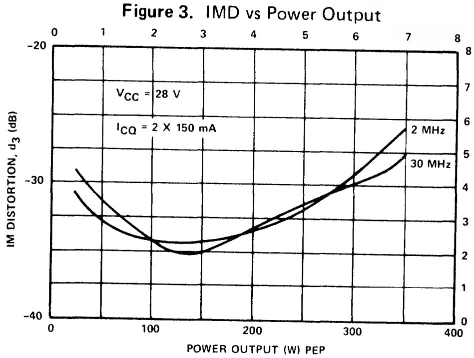



**Figure 3.** IMD vs Power Output




**MOTOROLA** *Semiconductor Products Inc.*

# A TWO-STAGE 1 KW SOLID-STATE LINEAR AMPLIFIER

Prepared by:
**Helge O. Granberg**

## INTRODUCTION

This application note discusses the design of 50 W and 300 W linear amplifiers for the 1.6 to 30 MHz frequency band. Both amplifiers employ push-pull design for low, even harmonic distortion. This harmonic distortion and the 50 Vdc supply voltage make the output impedance matching easier for 50-Ohm interface, and permits the use of efficient 1:1 and 4:1 broadband transformers.

Modern design includes integrated circuit bias regulators and the use of ceramic chip capacitors throughout the RF section, making the units easily mass producible.

Also, four 300 W modules are combined to provide a 1 to 1.2 kW PEP or CW output capability. The driver amplifier increases the total power gain of the system to approximately 34 dB.

Although the transistors employed (MRF427 and MRF428) are 100% tested against 30:1 load mismatches, in case of a slight unbalance, the total dissipation ratings may be well exceeded in a multi-device design. With high drive power available, and the power supply current limit set at much higher levels, it is always possible to have a failure in one of the push-pull modules under certain load mismatch conditions. It is recommended that some type of VSWR based protective circuitry be adapted in the equipment design, and separate dc regulators with appropriate current limits provided for each module.

The MRF428 is a single chip transistor with the die size of 0.140 x 0.248", and rated for a power output of 150 W PEP or CW. The single chip design eliminates the problem of selecting two matched die for balanced power distribution and dissipation. The high total power dissipation rating (320 W) has been achieved by decreasing the thermal resistance between the die and the mount by reducing the thickness of the BeO insulator to 0.04" from the standard 0.062", resulting in $R_{\theta JC}$ as low as 0.5°C/W.

The MRF427 is also a single chip device. Its die size is 0.118 x 0.066", and is rated at 25 W PEP or CW. This being a high voltage unit, the package is larger than normally seen with a transistor of this power level to prevent arcing between the package terminals.

The MRF427 and MRF428 are both emitter-ballasted, which insures an even current sharing between each cell, and thus improving the device ruggedness against load mismatches.

The recommended collector idling currents are 40 mA and 150 mA respectively. Both devices can be operated in Class A, although not specified in the data sheet, providing the power dissipation ratings are not exceeded.

## GENERAL DESIGN CONSIDERATIONS

Similar circuit board layouts are employed for the four 300 W building block modules and the preamplifier. A compact design is achieved by using ceramic chip capacitors, of which most can be located on the lower side of the board. The lead lengths are also minimized resulting in smaller parasitic inductances and smaller variations from unit-to-unit.

Loops are provided in the collector current paths to allow monitoring of the individual collector currents with a clip-on current meter, such as the HP-428B. This is the easiest way to check the device balance in a push-pull circuit, and the balance between each module in a system such as this.

The power gain of each module should be within not more than 0.25 dB from each other, with a provision made for an input Pi attenuator to accommodate device pairs with larger gain spreads. The attenuators are not used in this device however, due to selection of eight closely matched devices.

In regards to the performance specifications, the following design goals were set:

- Devices: 8 x MRF428 + 2 x MRF427A
- Supply Voltage: 40 – 50 V
- $\eta$, Worst Case: 45% on CW and 35% under two-tone conditions
- IMD, $d_3$: -30 dB Maximum (1 kW PEP, 50 V and 800 W PEP, 40 V)
- Power Gain, Total: 30 dB Minimum
- Gain Variation: 2.0 – 30 MHz: ±1.5 dB Maximum
- Input VSWR: 2.0:1 Maximum
- Continuous CW Operation, 1 kW: 50% Duty Cycle, 30-minute periods, with heatsink temperature <75°C.
- Load Mismatch Susceptibility: 10:1, any phase angle

Determining the figures above is based on previous performance data obtained in test circuits and broadband amplifiers. Some margin was left for losses and phase errors occurring in the power splitter and combiner.

## THE BIAS VOLTAGE SOURCE

Figure 1 shows the bias voltage source employed with each of the 300 W modules and the preamplifier. Its basic components are the integrated circuit voltage regulator MC1723C, the current boost transistor Q3 and the temperature sensing diode D1.

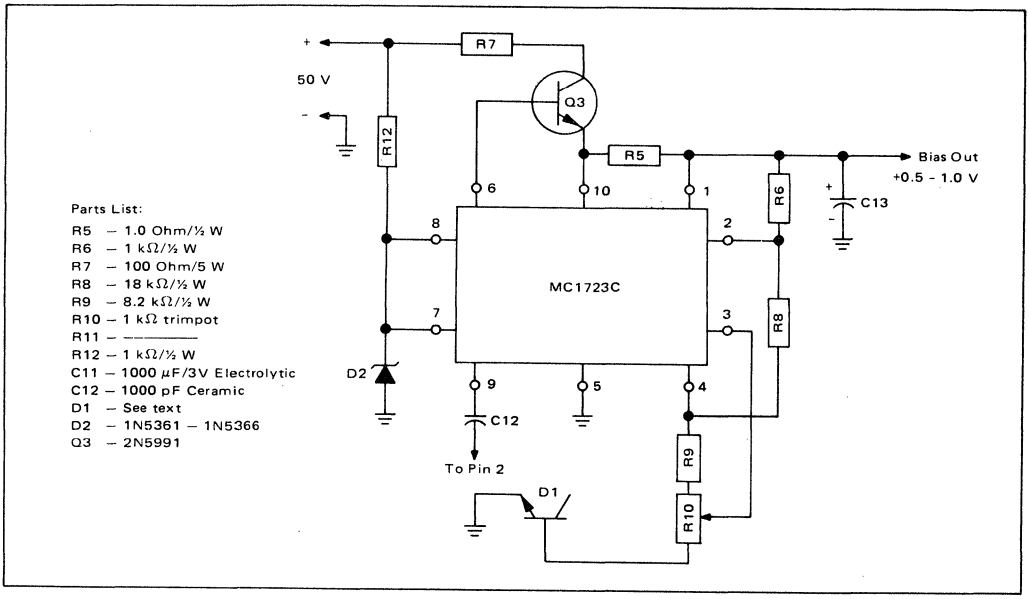



FIGURE 1 – Bias Voltage Source

Although the MC1723C is specified for a minimum $V_O$ of 2 Volts, it can be used at lower levels with relaxed specifications, which are sufficient for this application. Advantages of this type bias source are:

1. Line voltage regulation, which is important if the amplifier is to be operated from various supply voltages.
2. Adjustable current limit.
3. Very low stand-by current drain.

Figure 1 is modified from the circuit shown on the MC1723 data sheet by adding the temperature sensing diode D1 and the voltage adjust element R10. D2 and R12 reduce the supply voltage to a level below 40 V, which is the maximum input voltage of the regulator.

D1 is the base-emitter junction of a 2N5190, in a Case 77 plastic package. The outline dimensions allow its use for one of the circuit board stand-offs, attaching it automatically to the heatsink for temperature tracking.

The temperature compensation has a slight negative coefficient. When the collector idling current is adjusted to 300 mA at 25°C, it will be reduced to 240 – 260 mA at a 60°C heatsink temperature. (-1.15 to -1.7 mA/C°.)

The current limiting resistor R5 sets the limiting to approximately 0.65 A, which is sufficient for devices with a minimum $h_{FE}$ of 17, ($I_B = \frac{I_C}{h_{FE}}$) when the maximum average $I_C$ is 10.9 A. (2 MHz, 50 V, 250 CW.) Typically, the MRF428 $h_{FE}$'s are in the 30's.

The measured output voltage variations of the bias source (0 – 600 mA) are ±5 to 7 mV, which amounts to a source impedance of approximately 20 milliohms.

## THE 300 W AMPLIFIER MODULE

### Input Matching

Due to the large emitter periphery of the MRF428, the series base impedance is as low as 0.88, -J.80 Ohm at 30 MHz. In a push-pull circuit a 16:1 input transformer would provide the best impedance match from a 50-Ohm source. This would however, result in a high VSWR at 2 MHz, and would make it difficult to implement the gain correction network design. For this reason a 9:1 transformer, which is more ideal at the lower frequencies, was chosen. This represents a 5.55 Ohm base-to-base soure impedance.

In a Class C push-pull circuit, where the conduction angle is less than 180°, the base-to-base impedance would be about four times the base-to-emitter impedance of one device. In Class A where the collector idling current is approximately half the peak collector current, the conduction angle is 360°, and the base-to-base impedance is twice the input impedance of one transistor. When the forward base bias is applied, the conduction angle increases and the base-to-base impedance decreases rapidly, approaching that of Class A in Class AB.

A center tap, common in push-pull circuits, is not necessary in the input transformer secondary, if the transistors are balanced. ($C_{ib}$, $h_{FE}$, $V_{BEf}$.) The base current return path is through the forward biased base-emitter

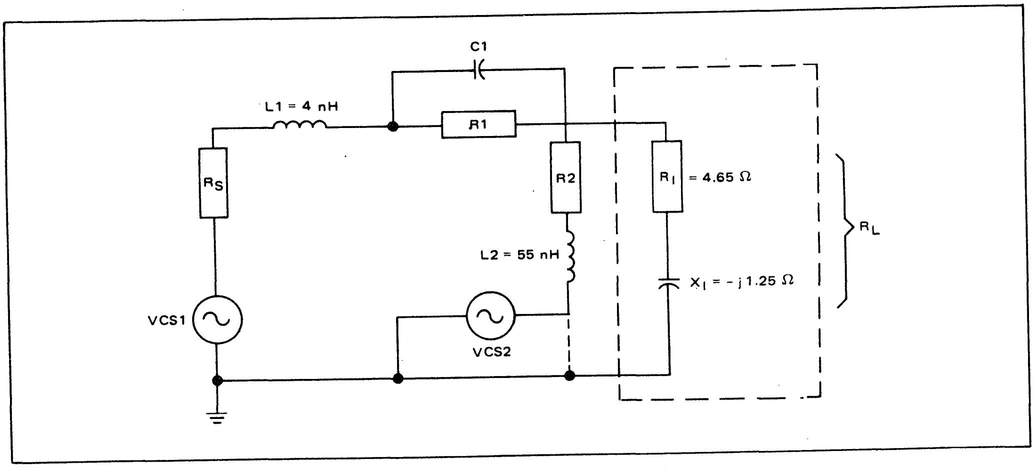



FIGURE 2 – Equivalent Base Input Circuit

junction of the off transistor. This junction acts as a clamping diode, and the power gain is somewhat dependent upon the amount of the bias current. The equivalent input circuit (Figure 2) represents one half of the push-pull circuit, and for calculations $R_S$ equals the total source impedance ($R_S'$) divided by two.

Since a junction transistor is a current amplifier, it should ideally be driven from a current source. In RF applications this would result in excessive loss of power gain. However, input networks can be designed with frequency slopes having some of the current source characteristics at low frequencies, where excess gain is available.

The complex base input characteristics of a transistor would place requirements for a very sophisticated input compensation network for optimum overall performance. The design goal here was to maintain an input VSWR of 2:1 or less and a maximum gain variation of ±1.5 dB from 2 to 30 MHz. Initial calculations indicated that these requirements can be met with a simple RC network in conjunction with negative collector-to-base feedback. Figure 2 shows this network for one device. L1 and L2 represent lead lengths, and their values are fixed. The feedback is provided through R2 and L2. Because the calculations were done without the feedback, this branch is grounded to simulate the operating conditions.

The average power gain variation of the MRF428 from 2 to 30 MHz is 13 dB. Due to phase errors, a large amount of negative feedback in an RF amplifier decreases the linearity, or may result in instabilities. Experience has shown that approximately 5 – 6 dB of feedback can be tolerated without noticeable effects in linearity or stability, depending upon circuit layout. If the amount of feedback is 5 dB, 8 dB will have to be absorbed by the input network at 2 MHz.

Omitting the reactive components, L1, L2, C1, and the phase angle of $X_I$ which have a negligible effect at 2 MHz, a simple L-pad was calculated with $R_S$ = 2.77 Ω, and $R_L = \sqrt{4.65^2 + 1.25^2} = 4.81\ \Omega$.

From the device data sheet we find the $G_{PE}$ at 2 MHz is about 28 dB, indicating 0.24 W at $R_L$ will produce an output power of 150 W, and the required power at $R_S$ = 0.24 W + 8 dB = 1.51 W.

Figuring out currents and voltages in various branches, results in: R1 = 1.67 Ω and R2 = 1.44 Ω.

The calculated values of R1 and R2 along with other known values and the device input data at four frequencies were used to simulate the network in a computer program. An estimated arbitrary value of 4000 pF for C1 was chosen, and VCS2 represents the negative feedback voltage (Figure 2.) The optimization was done in two separate programs for R1, R2, C1 and VCS2 and in several steps. The goals were: a) VCS and R2 for a transducer loss of 13 dB at 2 MHz and minimum loss at 30 MHz. b) R1 and C1 for input VSWR of <1.1:1 and <2:1 respectively. The optimized values were obtained as:

C1 = 5850 pF    R2 = 1.3 Ω
R1 = 2.1 Ω    VCS2 = 1.5 V

The minimum obtainable transducer loss at 30 MHz was 2.3 dB, which is partly caused by the highest reflected power at this frequency, and can be reduced by "over-compensation" of the input transformer. This indicates that at the higher frequencies, the source impedance ($R_S$) is effectively decreased, which leaves the input VSWR highest at 15 MHz.

In the practical circuit the value of C1 (and C2) was rounded to the nearest standard, or 5600 pF. For each half cycle of operation R2 and R4 are in series and the value of each should be $\frac{1.3\ \Omega}{2}$ for VCS2 = 1.5 V. Since the voltage across ac and bd = $V_{CE}$, a turns ratio of 32:1 would be required. It appears that if the feedback voltage

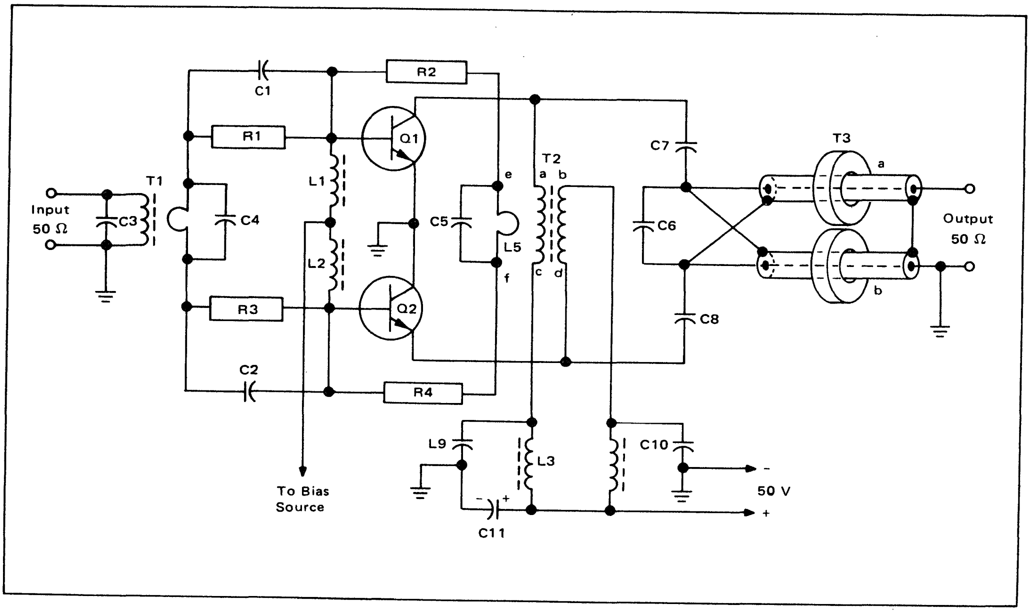



FIGURE 3

on the bases remains unchanged, the ratio of the voltage across L5 (VCS2) and R2R4 can be varied with only a small effect to the overall input VSWR. To minimize the resistive losses in the bifilar winding of T2 (Figure 3), the highest practical turns ratio should not be much higher than required for the minimum inductance, which is

$$\frac{4R}{2\pi f} = \frac{50}{12.5} = 4.0\ \mu H.$$

R = Collector-to-Collector Impedance = 12.5 Ω

f = 2 MHz

ac or bd will then be 1.0 $\mu$H, which amounts to 5 turns. (See details on T2.) 25% over this represents a 7:1 ratio setting VCS2 to 6.9 V.

In addition to providing a source for the negative feedback, T2 supplies the dc voltage to the collectors as well as functions as a center tap for the output transformer T3.

The currents for each half cycle are in opposite phase in ac and bd, and depending on the coupling factor between the windings, the even harmonic components will see a much lower impedance than the fundamental. The optimum line impedance for ac, bd would equal the collector-to-collector impedance, but experiments have shown that increasing this number by a factor of 2-3 affects the 2nd and 4th harmonic amplitudes by only 1 to 2 dB.

Since the minimum gain loss obtainable at 30 MHz with network as in Figure 2, and the modified VCS2 source was about 3.8 dB at 30 MHz, C5 was added with the following in mind: C5 and L5 form a parallel resonant circuit with a Q of approximately 1.5. Its purpose is to increase the shunting impedance across the bases, and to disturb the 180° phase difference between the input signal and the feedback voltage at the higher frequencies. This reduces the gain loss of 3.8 dB, of which 1.4 dB is caused by the feedback at 30 MHz. The amount depends upon the resonant frequency of C5 L5, which should be above the highest operating frequency, to avoid possible instabilities.

When L5 is 45 nH, and the resonance is calculated for 35 MHz, the value of C5 becomes 460 pF, which can be rounded to the closest standard, or 470 pF. The phase shift at 30 MHz is:

$$\mathrm{Tan}^{-1}\left[\frac{2\pi f L}{R\left(1 - \frac{f^2}{f_o^2}\right)}\right] = \mathrm{Tan}^{-1}\left[\frac{6.28 \times 30 \times 0.045}{6.8\left(1 - \frac{900}{1225}\right)}\right]$$

$$= \mathrm{Tan}^{-1}\left(\frac{8.48}{1.80}\right) = 78.0^o$$

The impedance is: $\frac{R}{\cos\theta} = \frac{6.8}{\cos 78^o} \doteq 32.7\ \Omega$

At 2 MHz the numbers are respectively 4.76° and 6.83 Ω.

The 1.4 dB feedback means that the feedback voltage is 16% of the input voltage at the bases. By the aid of

vectors, we can calculate that the 78° phase shift and the increased impedance reduces this to 4%, which amounts to 0.35 dB. These numbers were verified in another computer program with VCS2 = 6.9 V, and including C5. New values for R1 and R2 were obtained as 1.95 Ω and 6.8 Ω respectively, and other data as shown in Table 1.

The VSWR was calculated as

$$\frac{Z1 - Z2}{Z1 + Z2} \quad \text{where:}$$

Z1 = Impedance at transformer secondary.

**TABLE1:**

| Frequency MHz | Input VSWR | Input Impedance Real | Input Impedance Reactive | Attenuation dB |
|---|---|---|---|---|
| 2.0 | 1.07 | 2.79 | -0.201 | 13.00 |
| 4.0 | 1.16 | 2.66 | -0.393 | 12.07 |
| 7.5 | 1.33 | 2.35 | -0.615 | 10.42 |
| 15 | 1.68 | 1.77 | -0.611 | 7.40 |
| 20 | 1.82 | 1.57 | -0.431 | 5.90 |
| 30 | 1.74 | 1.62 | -0.21 | 2.70 |

Although omitted from the preliminary calculations, the 2 x 5 nH inductances, comprising of lead length, were included in this program.

The input transformer is a 9:1 type, and uses a television antenna balun type ferrite core, made of high permeability material. The low impedance winding consists of one turn of 1/8" copper braid. The sections going through the openings in the ferrite core are rounded to resemble two pieces of tubing electrically. The primary consists of AWG #22 TFE insulated wire, threaded through the rounded sections of braid, placing the primary and secondary leads in opposite ends of the core. (4) (5). The saturation flux density is about 60 gauss which is well below the limits for this core. For calculation procedures, see discussion about the output transformer.

This type physical arrangement provides a tight coupling, reducing the amount of leakage flux at high frequencies. The wire gauge, insulation thickness, and number of strands have a minimal effect in the performance except at very high impedance ratios, such as 25:1 and up. The transformer configuration is shown in Figure 4. By using a vector impedance meter, the values for C3 and C4 were measured to give a reasonable input match at 30 MHz, ($Z_{in}$ = 1.62 - j 0.21 x 2 = 3.24 - j 0.42) with the smallest possible phase angle.

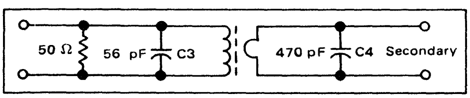



**FIGURE 4 — Transformer Configuration**

When the high impedance side was terminated into 50 Ω, the following readings were obtained at the secondary:

Z2 = Input impedance of compensation network x 2 ($R_S$ in Figures 2 and 3) as in computer data presented ahead.

The effect of the lower VSWR to the power loss in the input network can be calculated as follows:

$$10 \text{ Log} \left[ \frac{\left(1 - \left(\frac{S1 - 1}{S1 + 1}\right)^2\right)}{\left(1 - \left(\frac{S2 - 1}{S2 + 1}\right)^2\right)} \right]$$

where:
S1 = VSWR 1 (Lower)
S2 = VSWR 2 (Higher)

$$\text{which at 30 MHz} = 10 \text{ Log} \frac{\left(1 - \left(\frac{1.11 - 1}{1.11 + 1}\right)^2\right)}{\left(1 - \left(\frac{1.74 - 1}{1.74 + 1}\right)^2\right)}$$

$$= 10 \text{ Log} \left(\frac{0.997}{0.927}\right) = 0.32 \text{ dB}, 2.7 - 0.32 = 2.38 \text{ dB}$$

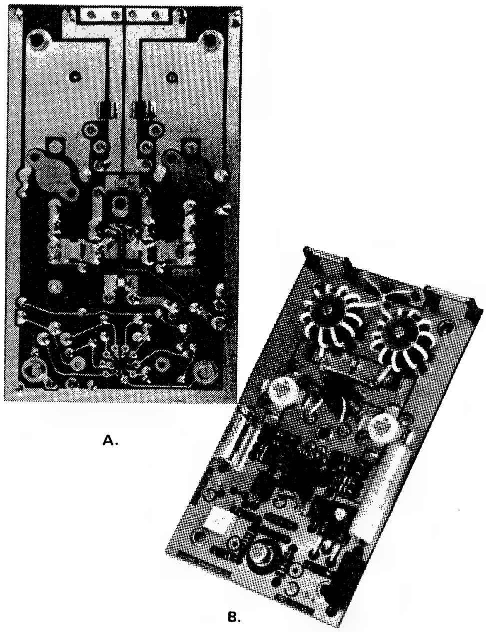
These figures for other frequencies are presented with the data below. Later, some practical experiments were done with moving the resonance of C5 L5 lower, to find out if instabilities would occur in a practical circuit. When the resonance was equal to the test frequency, slight break-up was noticed in the peaks of a two-tone pattern. It was then decided to adjust the resonance to 31 MHz, where C5 = 560 pF, and the phase angle at 30 MHz increases to 87°. The transducer loss is further reduced by about 0.2 dB.

Several types of output transformer configurations were considered. The 12.5 Ω collector-to-collector im-

**TABLE 2:**

| Frequency MHz | $R_S$ Ohms | $X_S$ Ohms | VSWR | Attenuation dB |
|---|---|---|---|---|
| 2.0 | 5.59 | +0.095 | 1.05 | 12.99 |
| 4.0 | 5.55 | +0.057 | 1.15 | 12.06 |
| 7.5 | 5.50 | +0.046 | 1.32 | 10.40 |
| 15 | 4.90 | +0.25 | 1.48 | 7.28 |
| 20 | 4.32 | +0.55 | 1.38 | 5.63 |
| 30 | 3.43 | +0.73 | 1.11 | 2.38 |

(Above readings with transformer and compensation network.)



A.

B.

**FIGURE 5 – Bottom and Top of the 300 W Module Circuit Board**

pedance estimated earlier, would require a 4:1 transformer for a 50 Ω output. The type used here as the input transformer exhibits good broad band characteristics with a convenient physical design. However, according to the low frequency minimum inductance formula presented earlier in connection with T2, the initial permeability required would be nearly 3000, with the largest standard core size available. High permeability ferrites are almost exclusively of Nickel-Manganese composition, and are lossy at radio frequencies. Although their Curie points are higher than those of lower permeability Nickel-Zinc ferrites, the core losses would degrade the amplifier performance. With the core losses being a function of the power level, these rules can sometimes be disregarded in low power applications.

A coaxial cable version was adapted for this design, since the transmission line type transformers are theoretically ideal for RF applications, especially in the 1:4 impedance ratio. A balanced to unbalanced function would normally require three separate transmission lines including a balun (5) (6). It appears that the third line can be omitted, if lines a and b (Figure 3) are wound on separate magnetic cores, and the physical length of the lines is sufficient to provide the necessary isolation between the collectors and the load. In accordance to formulas in (7), the minimum line length required at 2 MHz, employing Stackpole 57-9074 or equivalent ferrite toroids is 4.2", and the maximum permissible line length at 30 MHz would be approximately 20". The 4.2" amounts to four turns on the toroid, and measures 1.0 $\mu$H, which in series with the second line is sufficient for 2 MHz. Increasing the minimum required line length by a factor of 4 is still within the calculated limits, and in practical measurements the isolation has been found to be over 30 dB across the band. The main advantage with this arrangement is a simplified electrical and physical lay-out.

The maximum flux density of the toroids is approximately 200 gauss (3), and the number of turns has been increased beyond the point where the flux density of the magnetic core is the power limiting factor.

The 1:4 output transformer is not the optimum in this case, but it is the closest practical at these power levels. The optimum power output at 50 V supply voltage and 50 Ω load is:

$$V_{RMS} = 4 \times (V_{CC} - V_{CE(sat)} \times 0.707) = 135.75 \text{ V, when } V_{CE(sat)} = 2 \text{ V}$$

$$I = \frac{135.75}{50} = 2.715 \text{ A}, P_{out} = 2.715 \times 135.75 = 368.5 \text{ W}$$

The optimum $V_{CC}$ at $P_{out}$ = 300 W would be:

$$V_{CC} = V_{CE(sat)} + (\sqrt{R_{in} \times 2\,P_{out}}) = 2 + (\sqrt{6.25 \times 300}) = 45.3 \text{ V}$$

The above indicates that the amplifier sees a lower load line, and the collector efficiency will be lowered by 1-2%. The linearity at high power levels is not affected, if the device $h_{FE}$ is maintained at the increased collector currents. The linearity at low power levels may be slightly decreased due to the larger mismatch of the output circuit.

The required characteristic line impedance (a and b, Figure 3) for a 1:4 impedance transformer is: $\sqrt{R_{in}\,R_L} = \sqrt{12.5 \times 50} = 25\ \Omega$, enables the use of standard miniature 25 Ω coaxial cable (i.e., Microdot 260-4118-000) for the transmission lines. The losses in this particular cable at 30 MHz are 0.03 dB/ft. With a total line length of 2 x 16.8" (2 x 4 x 4.2"), the loss becomes 0.084 dB, or

$$300 - \left(\frac{300}{10 \text{ antilog } 0.084 \text{ dB}}\right) = 5.74 \text{ W}.$$

For the ferrite material employed, Stackpole grade #11 (or equivalent Indiana General Q1) the manufacturers data is insufficient for accurate core loss calculations (6). The $B_H$ curves indicate that 100-150 gauss is well in the linear region.

The toroids measure 0.87" x 0.54" x 0.25", and the 16.8" line length figured above, totals to 16 turns if tightly wound, or 12-14 turns if loosely wound. The flux density can then be calculated as:

$$B_{max} = \frac{V_{max} \times 10^2}{2\,\pi\,f\,n\,A}$$

where:
- f = Frequency in MHz
- n = Total number of turns.
- A = Cross sectional area of the toroid in $cm^2$.
- V = Peak voltage across the 50 Ω load, $\sqrt{\left(\frac{300}{50}\right)}\left(\frac{50}{0.707}\right) = 173$ V

$$B_{max} \text{ (for each toroid)} = \frac{86.5 \times 10^2}{6.28 \times 2 \times 28 \times .25} = 98.3 \text{ gauss}$$

Practical measurements showed the core losses to be negligible compared to the line losses at 2 MHz and 30 MHz. However, the losses increase as the square of $B_{max}$ at low frequencies.

With the amount of HF compensation dependent upon circuit layout and the exact transformer construction, no calculations were made on this aspect for the input (or output) transformers. C3, C4, and C6 were selected by employing adjustable capacitors on a prototype whose values were then measured.

A photo of the circuit board is shown in Figure 5, A-bottom and B-top. The performance data of the 300 W module can be seen in Figure 6.

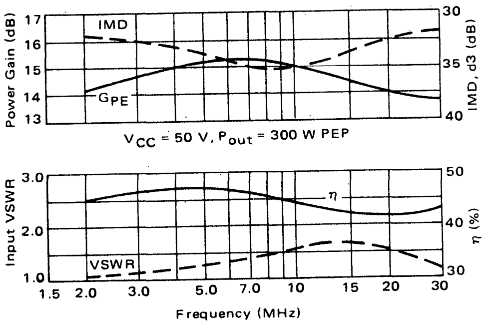



**FIGURE 6 – IMD, Power Gain, Input VSWR and Efficiency versus Frequency of a 300 W Module**

## THE DRIVER AMPLIFIER

The driver uses a pair of MRF427 devices, and the same circuit board layout as the power amplifier, with the exception of the type of the output transformer.

The input transformer is equal to what is used with the power amplifier, but has a 4:1 impedance ratio. The required minimum inductance in the one turn secondary (Figures 3 and 4) being considerably higher in this case,

$$\frac{4R}{2\pi f} = \frac{4 \times 12.5}{12.5} = 4\ \mu H$$

the $A_L$ product of the core is barely sufficient. The measured inductances between a number of cores range 3.8 - 4.1 $\mu$H.

This formula also applies to the output transformer, which is a 1:1 balun. The required minimum inductance at 2 MHz is 16 $\mu$H, amounting to 11 turns on a Ferroxcube 2616P-A100-4C4 pot core, which was preferred over a toroid because of ease of mounting and other physical features. Although twisted wire line would be good at this power level, the transformer was wound with RG-196 coaxial cable, which is also used later for module-driver interconnections.

The required worst case driver output is 4 x 12 W = 48 W. The optimum $P_{out}$ with the 1:1 output transformer is

$$\frac{V_{RMS}}{50} \times V_{RMS} = \frac{67.7}{50} \times 67.7 = 92\ W.$$

The MRF 427 is specified for a 25 W power output. Having a good $h_{FE}$ versus $I_C$ linearity, the 1 to 2 load mismatch has an effect of 2-3 dB in the IMD at the 10% power level, and the reduced efficiency in the driver is insignificant regarding the total supply current in the system.

The component values for the base input network and the feedback were established with the aid of a computer, and information on the device data sheet, as described earlier with the 300 W module. The HF compensation was done in a similar manner as well. Neither amplifier employs LF compensation. C7 and C8 are dc blocking capacitors, and their value is not critical.

In T2 (Figure 7), b and c represent the RF center tap, but are separated in both designs – partly because of circuit lay-out convenience and partly for stabilization purposes.

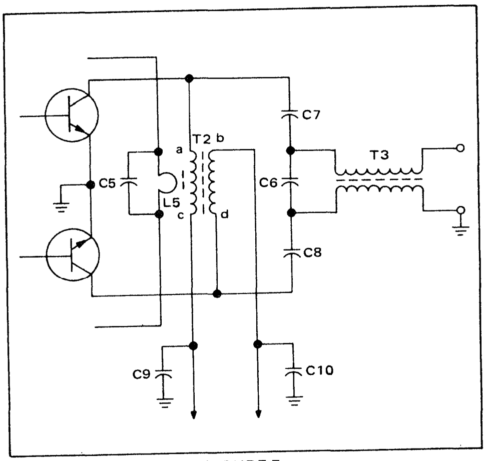



**FIGURE 7**

The test data of the driver is presented later along with the final test results.

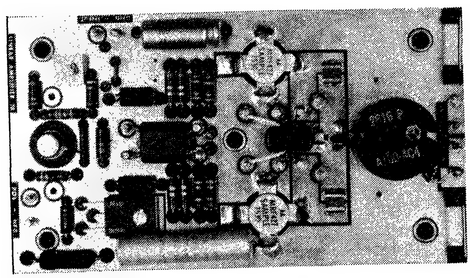


**FIGURE 8 – Driver Amplifier Board Layout**

## COMBINING FOUR 300 W POWER MODULES

### The Input Power Divider

The purpose of the power divider is to divide the input power into four equal sources, providing an amount of isolation between each. The outputs are designed for 50 Ω impedance, which sets the common input at 12.5 Ω. This requires an additional 4:1 step down transformer to provide a 50 Ω load for the driver amplifier. Another requirement is a 0° phase shift between the input and the 50 Ω outputs, which can be accomplished with 1:1 balun transformers. (a, b, c and d in Figure 10.) For im-

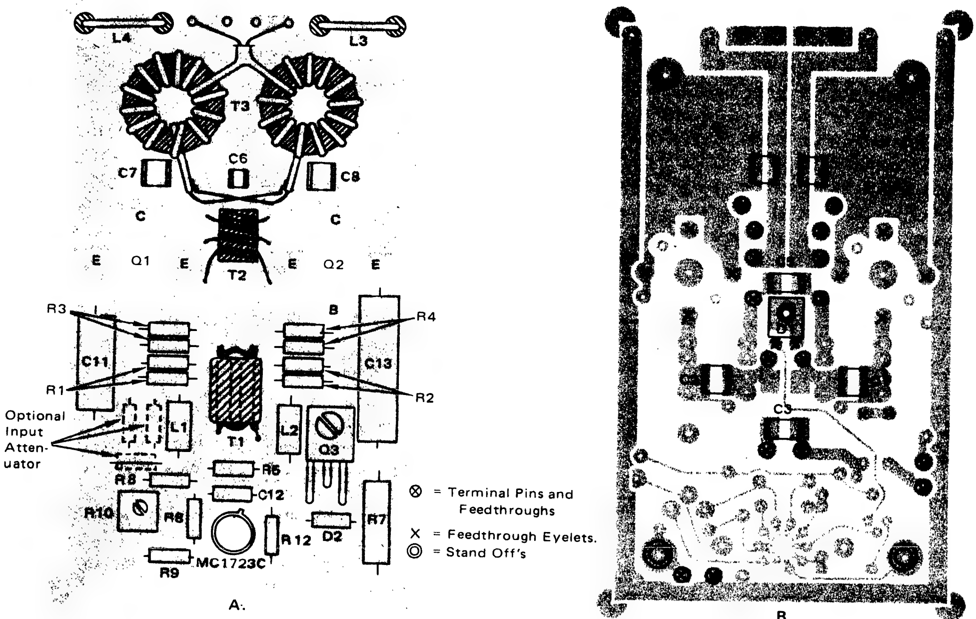



FIGURE 9 – Component Layout of the 300 W Amplifier Module

**PARTS LIST**
**(Power Module and Driver Amplifier)**

| | Power Module | Driver Amplifier |
|---|---|---|
| C1, C2 | 5600 pF | 3300 pF |
| C3 | 56 pF | 39 pF |
| C4 | 470 pF | Not Used |
| C5 | 560 pF | 470 pF |
| C6 | 75 pF | 51 pF |
| C7, C8 | 0.1 μF | 0.1 μF |
| C9, C10 | 0.33 μF | 0.33 μF |
| C11 | 10 μF/150 V | 10 μF/150 V |
| R1, R2 | 2 x 3.9 Ω/½ W in parallel | 2 x 7.5 Ω/½ W in parallel |
| R3, R4 | 2 x 6.8 Ω/½ W in parallel | 2 x 18 Ω/½ W in parallel |
| L1, L2 | Ferroxcube VK200 19/4B ferrite choke | Ferroxcube VK 200 19/4B ferrite choke |
| L3, L4 | 6 ferrite beads each, Ferroxcube 56 590 65/3B | 6 ferrite beads each, Ferroxcube 56 590 65/3B |
| | All capacitors, except C11, are ceramic chips. Values over 100 pF are Union Carbide type 1225 or 1813 or Varadyne size 18 or 14. Others ATC Type B. | |
| T1 | 9:1 type, see text. | 4:1 type, see text. |
| | (Ferrite cores for both: Stackpole 57-1845-24B or Fair-Rite Products 287300201 or equivalent.) | |
| T2 | 7 turns of bifilar or loosely twisted wires. (AWG #20.). Ferrite cores for both: Stackpole 57-9322, Indiana General F627-8Q1 or equivalent. | |
| T3 | 14 turns of Microdot 260-4118-00 25 Ω miniature coaxial cable wound on each toroid. (Stackpole 57-9074, Indiana General F624-19Q1 or equivalent.) | 11 turns of RG-196, 50 Ω miniature coaxial cable wound on a bobbin of a Ferroxcube 2616P-A100-4C4 pot core. |

proved low frequency isolation characteristics the line impedance must be increased for the parallel currents. This can be done, without affecting the physical length of the line, by loading the line with magnetic material. In this type transformer, the currents cancel, making it possible to employ high permeability ferrite and a relatively short physical length for the transmission lines. In an absolutely balanced condition, no power will be dissipated in the magnetic cores, and the line losses are reduced. The minimum required inductance for each line can be calculated as shown for the driver amplifier output transformer, which gives a number of 16 $\mu$H minimum at 2 MHz. A low inductance value degrades the isolation characteristics between the 50 Ω output ports, to maintain a low VSWR in case of a change in the input impedance of one or more of the power modules. However, because of the base compensation networks, the power splitter will never be subjected to a completely open or shorted load.

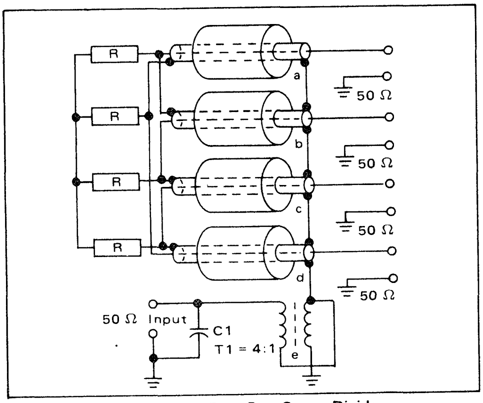



FIGURE 10 – Four Port Power Divider

The purpose of the balancing resistors (R) is to dissipate any excess power, if the VSWR increases. Their optimum values, which are equal, are determined by the number of 50 Ω sources assumed unbalanced at one time, and the resistor values are calculated accordingly.

Examining the currents with one load open, it can be seen that the excess power is dissipated in one resistor in series with three parallel resistors. Their total value is 50 - 12.5 – 37.5 Ω. Similarly, if two loads are open, the current flows through one resistor in series with two parallel resistors, totaling 37.5 Ω again. This situation is illustrated in Figure 11.

Except for a two port power divider [5], the resistor values can be calculated for odd or even number systems as:

$$R = \left(\frac{R_L - R_{in}}{n+1}\right) n \quad \text{where:}$$

$R_L$ = Impedance of the output ports, 50 Ω.
$R_{in}$ = Impedance of the input port, 12.5 Ω.
n = Number of output ports properly terminated.

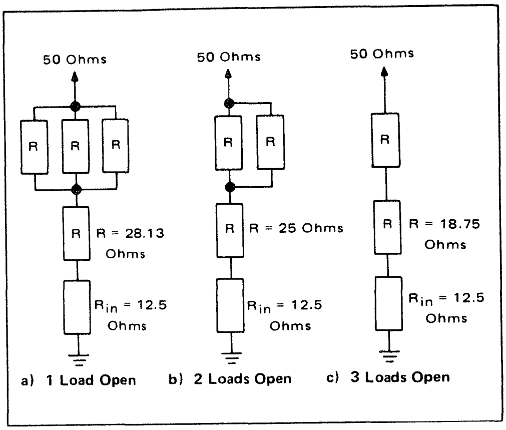



FIGURE 11

Although these resistor values are not critical in the input divider, the formula also applies to the output power combiner, where mismatches have a larger effect in the total power output and linearity.

The practical power divider employs large ferrite beads (Fair-Rite Products 2673000801 or Stackpole 57-1511-24B or equivalent) over a 1.2 inch piece of RG-196 coaxial cable. The arrangement is shown in Figure 10. Both above ferrite materials have a $\mu$r of about 2500, and the inductance for one turn is in excess of 10 $\mu$H.

The step-down transformer (T1, Figure 10) is wound on a Stackpole 57-9322-11 toroid with 25 Ω miniature coaxial cable. (Microdot 260-4118-000 or equivalent.) Seven turns will give a minimum inductance of 4/16 $\mu$H, required at 2 MHz.

For the preamplifier interface, C1 could be omitted in order to achieve the lowest input VSWR.

The structure is mounted between two phenolic terminal strips as can be seen in the foreground of Figure 14, providing a sufficient number of tie points for the coaxial cable connections.

### THE OUTPUT COMBINER

The operation of the output combiner is reversed from that of the input power divider. In this application we have four -50 Ω inputs and one 12.5 Ω output, which is transformed to 50 Ω by a 1:4 impedance ratio transformer.

An arrangement similar to the input power divider is employed in the combiner. The baluns consist of straight pieces of coaxial cable loaded by a sleeve of magnetic material (ferrite). The line length is determined by the physical dimensions of the ferrite sleeves. The $\mu$r versus cross sectional area should be calculated or measured to give sufficient loading inductance.

Straight line baluns as these have the advantage over multiturn toroidal types in introducing a smaller possibility for phase errors, due to the smaller length of the line. The largest possible phase errors occur in the input

and output connecting cables, whose lengths are 18" and 10" respectively. All four input and output cables must be of equal length within approximately ¼", and the excess in some, caused by the asymmetrical system layout, can be coiled or formed into loops.

The output connecting cables between the power amplifier outputs and the combiner are made of low loss RG-142B/U coaxial cable, that can adequately handle the 300 W power with the average current of 2.45 A.

The balun transmission lines are also made of RG-142B/U coaxial cable, with an outer diameter of 0.20". The line length is not critical as it is well below the maximum length permitted for 30 MHz (7). The minimum inductance, as in the input divider, is 16 μH per line. Measurements were made between two port combiners, one having the line inductance of 17 μH (7 Ferroxcube 768 series 3E2A toroids) and the other 4.2 μH (one Stackpole 57-0572-27A ferrite sleeve). The results are shown in Table 3.

The power output with various numbers of disabled sources, referring to Figures 11 and 12 can be calculated as:

$$P_n - P_R + \frac{P_R}{n}$$

where: n = Number of Operative Sources.
$P_n$ = Total Power of Operative Sources.
$P_R$ = Power Dissipated in Balancing Resistors.

For one disabled source:

$$P_R = 250\left(\frac{28.13}{50}\right) = 140.65,$$

$$P_{out} = (250 \times 3) - \left(140.65 + \frac{140.65}{3}\right) =$$

$$750 - 187.5 = 562.5 \text{ W}$$

This is assuming that the phase errors between the active sources are negligible. Otherwise the formula in (7) can

| f MHz | Isolation dB (Line Inductance 17 μH) | Isolation dB Line Inductance 4.2 μH) |
|---|---|---|
| 2.0 | 40.2 | 29.1 |
| 4.0 | 40.0 | 38.3 |
| 7.5 | 39.6 | 39.1 |
| 15 | 37.5 | 37.8 |
| 20 | 35.8 | 36.2 |
| 30 | 33.4 | 33.5 |

**TABLE 3:**

The main difference is at 2 MHz – and it was decided that the 29 dB of isolation is sufficient, as the high frequency isolation in either case is not much better. The 3E2A and other similar materials are rather lossy at RF, and with their low Curie points, would present a danger of overheating in case of a source unbalance.

Figure 12 shows the electrical design of the four-port power combiner.

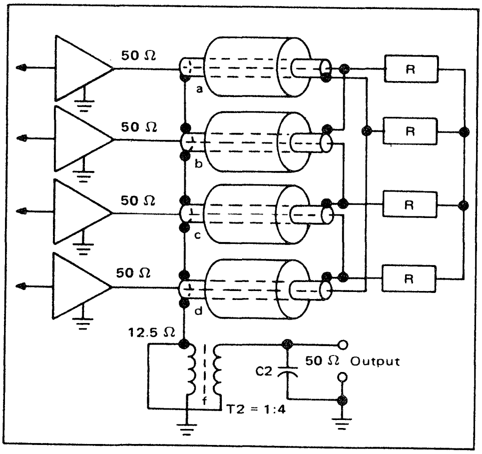



**FIGURE 12 – Four Port Output Combiner**

be adapted, but if the errors between the active sources are unequal, the situation will get rather complex.

From above we see that 140.65 W will be dissipated by one of the balancing resistors and only 15.6 W by the other three. For this high power dissipation the resistors must be the type which can be mounted to a heat sink, and noninductive. After experiments with the "non-inductive" wirewound resistors which exhibited excess inductance at 30 MHz and were bulky with 50 and 100 W ratings, thin film terminations were specially fabricated in-house for this application.* These terminations are deposited on a BeO wafer, which is attached to a copper flange. They are rated for 50 W continuous power, but can be operated at 100 or even 150 W for nonextended periods if the flange temperature is kept moderately low. The balancing resistors can be seen on the upper side of the combiner, which is shown in the foreground of Figure 15.

The purpose of the step-up transformer T2, (Figure 12) is to transform the 12.5 Ω impedance from the combiner up to 50 Ω. It is a standard 1:4 unbalanced-to-unbalanced transmission line type transformer, (6, 7, 8) in which the line is made of two RG-188 coaxial cables connected in parallel in the manner as shown in Figure 13.

Normally the loss in RG-188 at 30 MHz is 0.08 dB/foot. In this connection arrangement, the currents in both directions are carried by the braid in parallel with the

*Similar attenuators and terminations are available from Solitron, EMC Technology, Inc., and other manufacturers of microwave components.

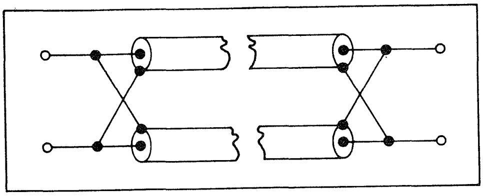


FIGURE 13

inner conductor and the power loss is reduced to approximately 0.025 dB/foot. The impedance becomes 25 Ω, and depending on how close the cables are to each other physically, it can be as low as 22 Ω. The minimum line inductance can be calculated as shown before, and is 16 μH for the 50 Ω side. This inductance is achieved by winding several turns of the dual cable line on a magnetic core. In contrast to the balun transformers in the combiner, the line currents do not cancel and the magnetic core must handle the full power, and must be made of lower loss material. The form of a toroid was figured to require the shortest line length for a specific inductance, and out of the standard sizes, two stacked units resulted in a shorter line length than a single larger one with similar cross sectional area.

Six turns on two Indiana General F626-12-Q1 toroids give 4.8 and 23 μH for the secondary; the line length being 16 inches.

In continuous operation the core temperature was measured as 95-90°C. This resulted in a decision to change the core material to Q2, which exhibits about 70% lower losses at 30 MHz. The permeability is also lower (35), and with the same number of turns gives only 13 μH.

The line length could not be increased according to (7), and the measurements indicated no difference in operation at 2 MHz, so the Q2 toroids with the low inductance were considered permanent.

The maximum flux density of the toroids is calculated as shown before:

$$B_{max} = \frac{V_{max} \times 10^2}{2\pi f \eta A} \text{ gauss, where:}$$

V = Peak voltage across the secondary, (50 point) 316.2 V
f = Frequency in MHz (2.0)
$\eta$ = Number of turns at the 50 Ω point. (12)
A = Core cross sectional area (1.21 cm$^2$)

$$B_{max} = \frac{316.2 \times 10^2}{6.28 \times 2 \times 12 \times 1.21} = 260 \text{ gauss}$$

From the BH curves we can see that the linear portion extends to 800-1000 gauss, and the saturation occurs at over 3000 gauss. Comparable materials are Stackpole grade 14 and Fair-rite products 63.

The core losses are minimal compared to the line losses, which for the 16" length amount to 0.035 dB or 0.81%.

As in the input transformer, the HF compensation (C2) was not required. The lay-out of the combiner and T2 is

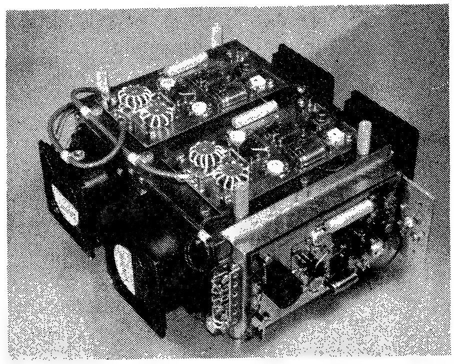


FIGURE 14 – 1 kW Linear Amplifier showing the input power divider in the foreground, to the right is the preamplifier. Two of the four 300 W modules can be seen on the upper side of the structure. The other two modules are shown in Figure 15.

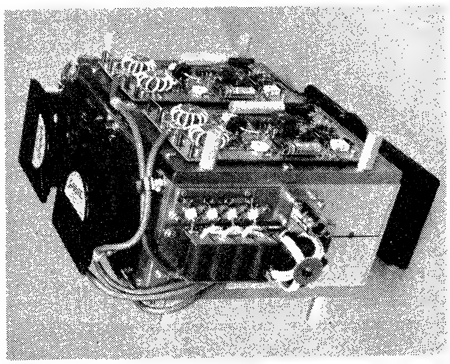


FIGURE 15 – 1 kW Linear Amplifier showing the output combiner in the foreground, to the right is the 1:4 stepup transformer. The four balancing resistors, mounted to the heat sink, can be seen directly above the combining network.

such that minimum lead lengths are obtained, and the structure is mounted on a PC board having feedthrough eyelets to a continuous ground plane on its lower side.

## MEASUREMENTS

Six 300 W modules were built using matched pair production MRF428's. The maximum gain distribution was 0.9 dB, and in the four units selected for the amplifier, the gain varied from 13.7 to 14.1 dB at 30 MHz, so it was not necessary to utilize the option of the input attenuators.

Figure 16 shows the test set-up arrangement employed for testing the modules and the combined amplifier.

The heatsink design was not optimized as it was felt to be outside the scope of this report; concentration was made in the electrical design. However, it was calculated to be sufficient for short period testing under two-tone or CW conditions at full power. The heatsink consists of

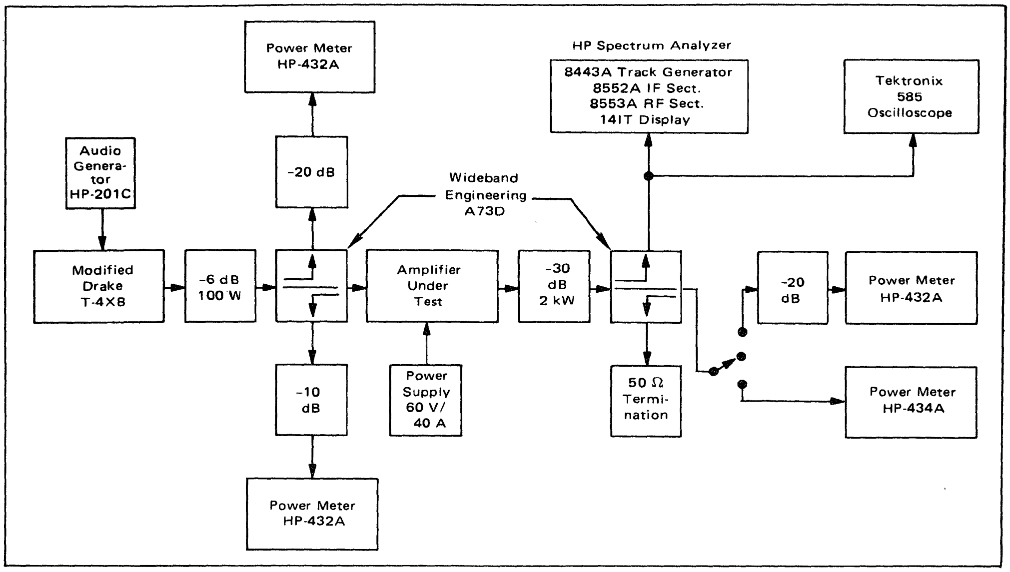



**FIGURE 16** — For two tone operation, a signal from an external audio oscillator is added to a signal from the T-4XB built-in oscillator, which has been adjusted to 800 Hz.

During single tone testing, the external oscillator (1200 Hz) is switched off. A calorimeter wattmeter in the output can be used to calibrate the HP-432A's at frequencies below ≈10 MHz, where their response roll-off begins.

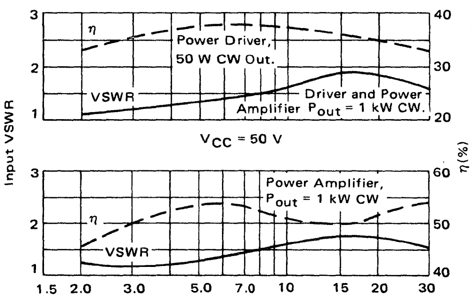



**FIGURE 17** — VSWR and Efficiency versus Frequency

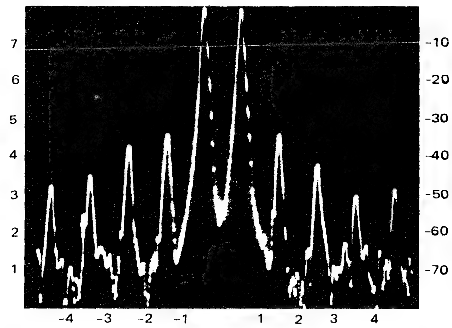



**FIGURE 19** — Photo of Spectrum Analyzer Display Showing the IMD Products to the 9th Order. Power Output = 1 kW at 30 MHz (50 V).

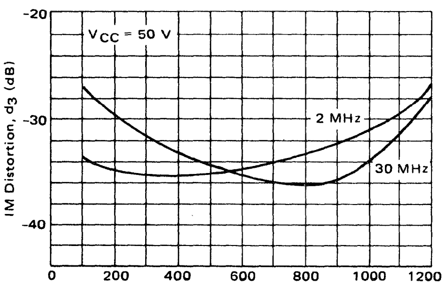



**FIGURE 18** — IMD versus Power Output

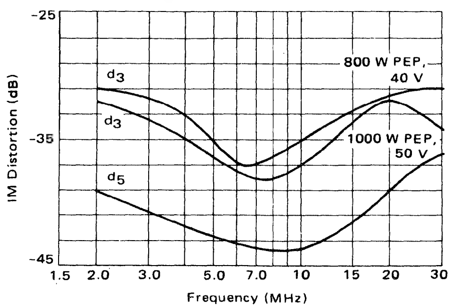



**FIGURE 20** — IMD versus Frequency

four 9" lengths of Thermalloy 6151 extrusion, each having a free air thermal resistance of 0.7°C/W. They are bolted in pairs to two 9" x 8½" x 3/8" copper plates, to which the four power modules are mounted. Assuming a coefficient of 0.85 between two parallel extrusions, a total thermal resistance of 0.4°C/W is realized. Two of these dual extrusions are mounted back-to-back to provide

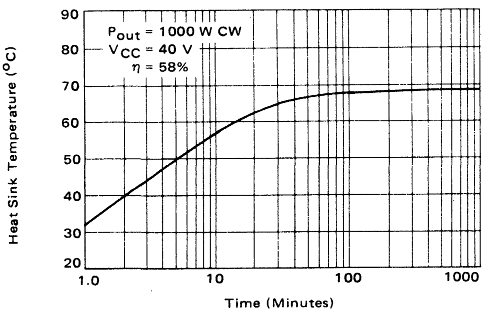



FIGURE 21 – Heat Sink Temperature versus Time

a channel for the air flow from four Rotron SP2A2 4" fans. Two are mounted in each end of the heatsink, and the four fans operating in the same direction provide an air flow of approximately 150 CFM.

The third order harmonic is 14 dB below the fundamental at certain frequencies, as can be seen in Figure 22. This number is typical in a four octave amplifier, and it is obvious that some type of output filter is required when it is used for communications purposes.

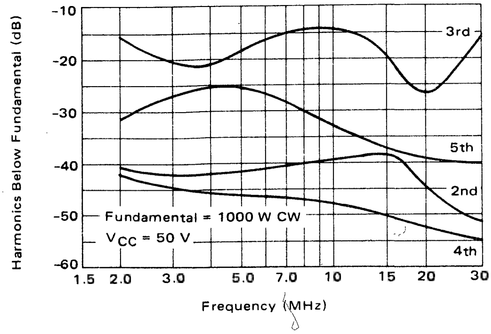



FIGURE 22 – Output Harmonic Contents versus Frequency

The 10:1 load mismatch was simulated with 34 feet of RG-58 coaxial cable, which has an attenuation of approximately 0.9 dB at 30 MHz, representing 1.8 dB return loss. The coaxial was terminated into an LC network consisting of a 2 x 15 – 125 pF variable capacitor and two inductors as shown in Figure 23.

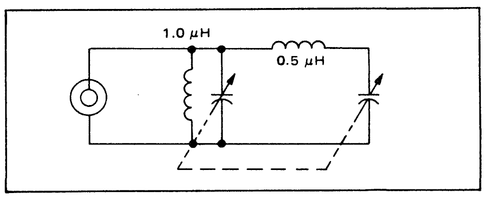



FIGURE 23 – Load Mismatch Test Circuit

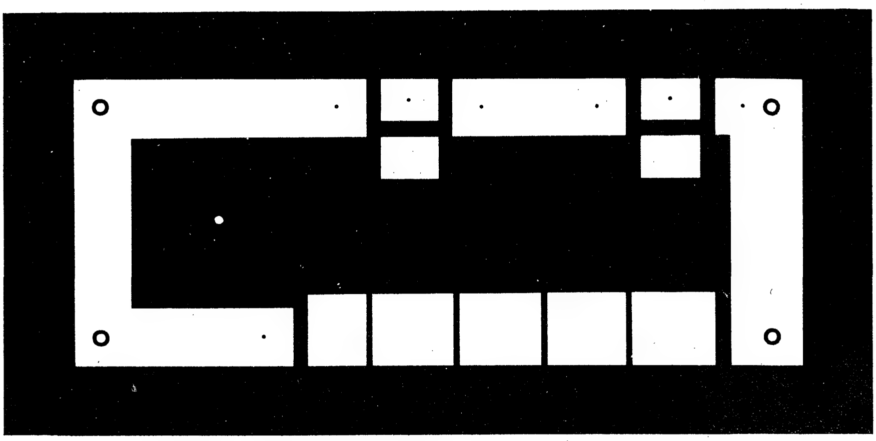


FIGURE 24 – Circuit Board Layout of the Power Combiner Assembly

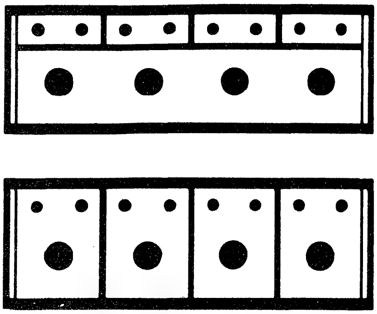


FIGURE 25 – Board Layout of the Power Combiner Transmission Line Assembly

The high current mode appears at a phase angle of $-90^{\circ}$ and 20 Ω, where the monitored individual collector currents increased to 6.8 A. At 50 V this amounts to 340 W, which almost entirely represents device dissipation.

At 20:1 load mismatch an equal power dissipation is reached at a power output of approximately 650 W CW.

Since the collector voltages remain below the device breakdowns at the high impedance mode ($+90^{\circ}$, 150 Ω), it may be concluded, that the load mismatch suspectability is limited by overdissipation of the transistors.

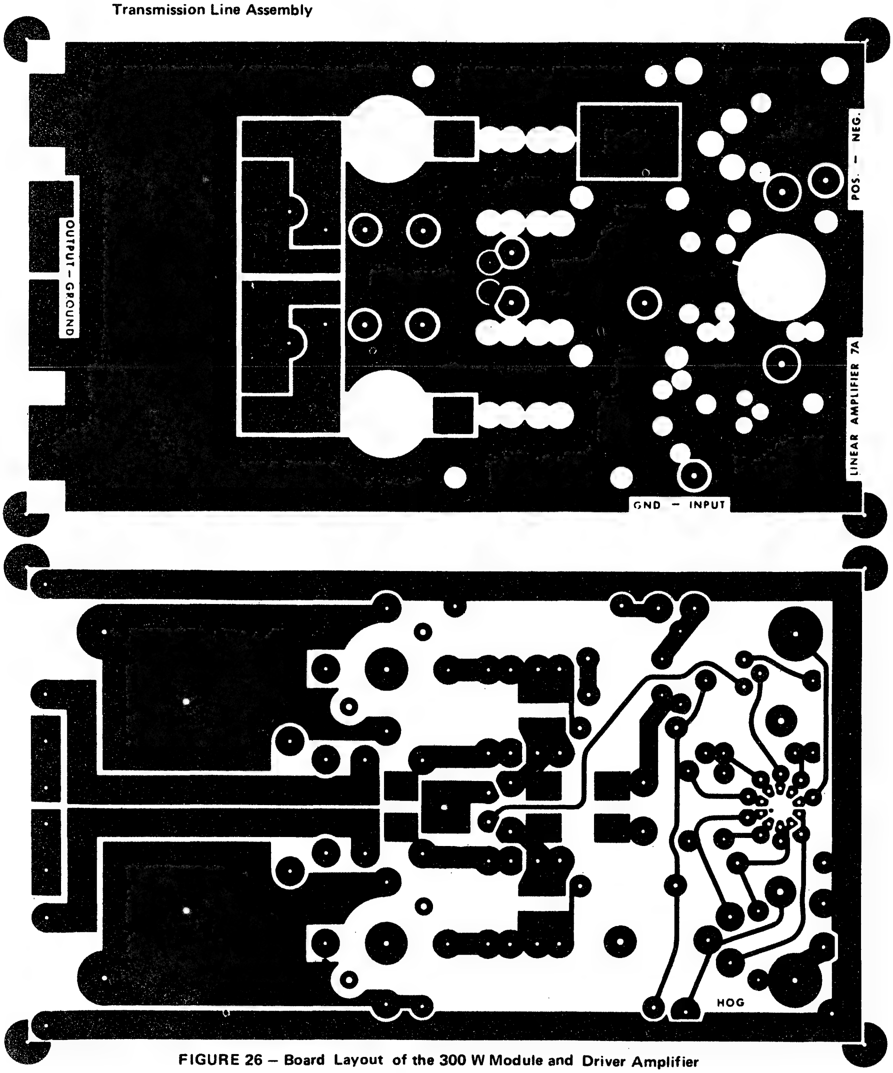



FIGURE 26 – Board Layout of the 300 W Module and Driver Amplifier

## REFERENCES


1. Ruthroff: Some Broad Band Transformers, *IRE, Volume 47,* August 1975.
2. Lewis: *Notes on Low Impedance H.F. Broad Band Transformer Techniques,* Collins Radio Company, November 1964.
3. Granberg, H.: *Broadband Linear Power Amplifiers Using Push-Pull Transistors,* AN-593, Motorola Semiconductor Products Inc.
4. Granberg, H.: *Get 300 Watts PEP Linear Across 2 to 30 MHz From This Push-Pull Amplifier,* EB-27, Motorola Semiconductor Products Inc.
5. Granberg, H.: *Broadband Transformers and Power Combining Techniques for RF,* AN-749, Motorola Semiconductor Products Inc.
6. Hilbers: Design of H.F. Wideband Power Transformer Techniques, *Phillips Application Information #530.*
7. Pizalis-Couse: Broadband Transformer Design for RF Transistor Amplifiers, *ECOM-2989,* U.S. Army Electronics Command, Fort Monmouth, New Jersey, July 1968.
8. *Philips Telecommunication Review,* Volume 30, No. 4, pp. 137-146, November 1972.
9. Lefferson: Twisted Wire Transmission Line, *IEEE Transactions on Parts, Hybrids and Packaging,* Volume PHP-7, No. 4, December 1971.
10. Krauss-Allen: Designing Toroidal Transformers to Optimize Wideband Performance, *ELECTRONICS,* August 1973.

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# MRF449
# MRF449A

## The RF Line

30 W – 30 MHz

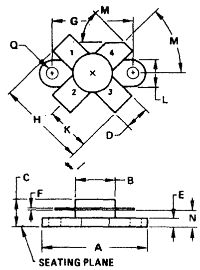
RF POWER
TRANSISTORS

NPN SILICON

## NPN SILICON RF POWER TRANSISTORS

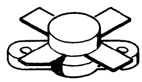
. . . designed for power amplifier application in industrial, commercial and amateur radio equipment to 30 MHz.

- Specified 13.6 Volt, 30 MHz Characteristics –
  Output Power = 30 Watts
  Minimum Gain = 12 dB
  Efficiency = 50%

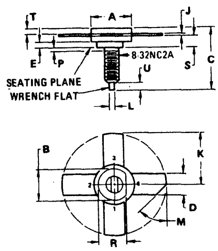



| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07
MRF449

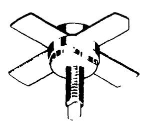


STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09
MRF449A



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 60<br>343 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

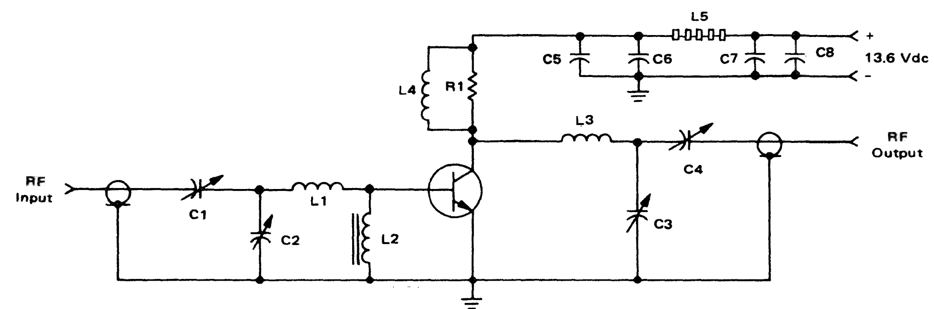
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.9 | °C/W |

5

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 40 | 50 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 20 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 140 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, $I_C$(max) = 4.0 Adc, f = 30 MHz) | $G_{PE}$ | 12 | 14 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, $I_C$(max) = 4.0 Adc, f = 30 MHz) | $\eta$ | 50 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, f = 30 MHz) | $Z_{in}$ | – | 2.13-j1.15 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, f = 30 MHz) | $Z_{out}$ | – | 2.47-j0.37 | – | Ohms |

FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC




C1 – 14-150 pF, ARCO 424
C2,C3,C4 – 170-780 pF, ARCO 469
C5,C8 – ERIE 0.1 μF @ 100 V RED CAPS
C6 – 1000 pF UNELCO, 350 Vdc
C7 – 10 μF, 35 Vdc
R1 – 100 Ω, 2 W Carbon
L1 – 0.15 μH Molded Choke MILLER
L2 – FERROXCUBE, VK200-20-4B
L3 – 3 Turns, #14 Bare Tinned Wire, 0.3" (0.79) I.D. x 0.38" (0.97) Long
L4 – 9 Turns, #20 Enamal Wire, Close Wound on R1
L5 – FERROXCUBE #56-570-65/3B, 5 Ferrite Beads, on 1" Long #20 Wire
Input/Output Connectors – Type N
Board – Glass Teflon Mounted on a 4" x 4" x 2" SEEZAK Box

FIGURE 2 – POWER OUTPUT versus POWER INPUT

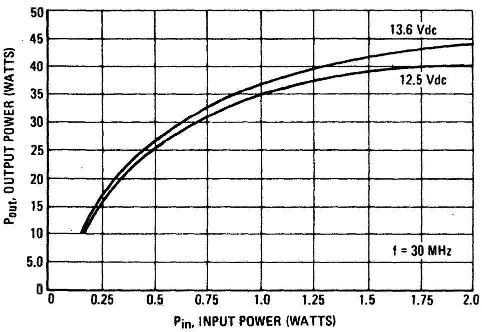
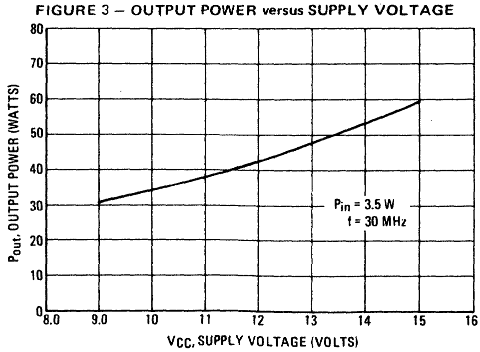



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE




5

**MOTOROLA**
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# MRF450
# MRF450A

## The RF Line

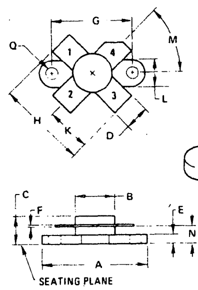
5

### NPN SILICON RF POWER TRANSISTORS

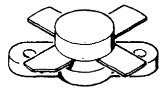
. . . designed for power amplifier applications in industrial, commercial and amateur radio equipment to 30 MHz.

- Specified 13.6 Volt, 30 MHz Characteristics –
  Output Power = 50 Watts
  Minimum Gain = 11 dB
  Efficiency = 50%

**50 W – 30 MHz**
**RF POWER TRANSISTORS**
**NPN SILICON**

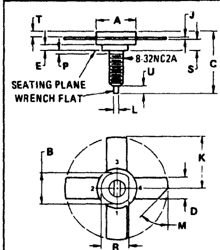



**MRF450**
**Case 211-09**

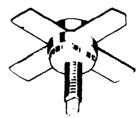


STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.29 | 2.79 | 0.090 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 11.05 | – | 0.435 | – |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 45° NOM | | 45° NOM | |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |




**MRF450A**



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 7.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 115<br>0.66 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | $-65^o$ to $+200^o$ | °C |

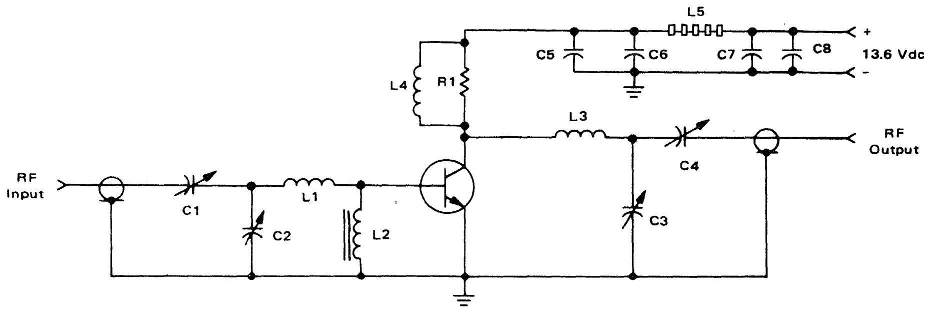
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.53 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 40 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 20 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 200 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 50 W, $I_C$(max) = 6.13 Adc, f = 30 MHz) | $G_{PE}$ | 11 | 15 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 50 W, $I_C$(max) = 6.13 Adc, f = 30 MHz) | $\eta$ | 50 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 50 W; f = 30 MHz) | $Z_{in}$ | – | 1.56-j.89 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 50 W, f = 30 MHz) | $Z_{out}$ | – | 174-j.50 | – | Ohms |

FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC




C1 – 14-150 pF, ARCO 424
C2,C3,C4 – 170-780 pF, ARCO 469
C5,C8 – ERIE 0.1 μF @ 100 V RED CAPS
C6 – 1000 pF UNELCO, 350 Vdc
C7 – 10 μF, 35 Vdc
R1 – 100 Ω, 2 W Carbon
L1 – 0.15 μH Molded Choke MILLER
L2 – FERROXCUBE, VK200-20-4B
L3 – 3 Turns, #14 Bare Tinned Wire, 0.3" (0.79) I.D. x 0.38" (0.97) Long
L4 – 9 Turns, #20 Enamal Wire, Close Wound on R1
L5 – FERROXCUBE #56-570-65/3B, 5 Ferrite Beads, on 1" Long #20 Wire
Input/Output Connectors – Type N
Board – Glass Teflon Mounted on a 4" x 4" x 2" SEEZAK Box

FIGURE 2 – INPUT POWER versus OUTPUT POWER

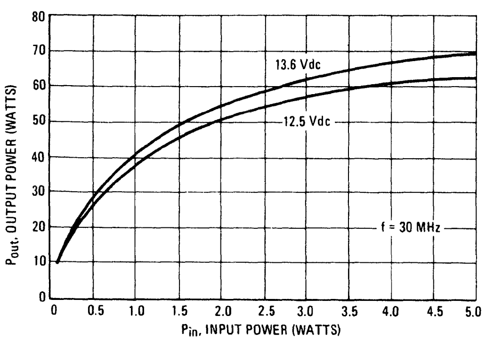
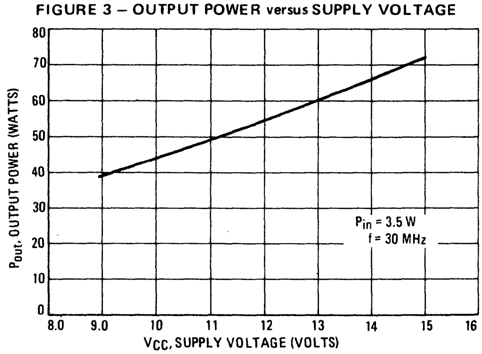



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE



**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF453
# MRF453A

## Advance Information

## The RF Line

**60 W – 30 MHz**
**RF POWER TRANSISTORS**
**NPN SILICON**

### NPN SILICON RF POWER TRANSISTORS

. . . designed for power amplifier applications in industrial, commercial and amateur radio equipment to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 60 Watts
  Minimum Gain = 13 dB
  Efficiency = 55%

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Emitter Voltage | $V_{CES}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 15 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 175<br>1.0 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

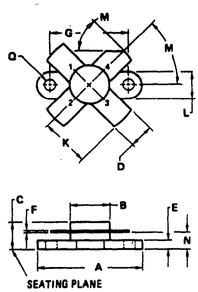
### THERMAL CHARACTERISTICS

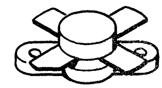
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.0 | °C/W |

### MATCHING PROCEDURE

In the push-pull circuit configuration, it is preferred that the transistors are used as matched pairs to obtain optimum performance.

The matching procedure used by Motorola consists of measuring $h_{FE}$ at the data sheet conditions and color coding the device to predetermined $h_{FE}$ ranges within the normal $h_{FE}$ limits. A color dot is added to the marking on top of the cap. Any two devices with the same color dot can be paired together to form a matched set of units.



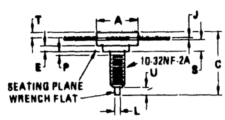



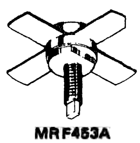
MRF453

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

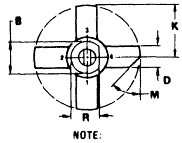
| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 11.81 | 12.95 | 0.465 | 0.510 |
| C | 5.82 | 6.98 | 0.229 | 0.275 |
| D | 5.46 | 5.97 | 0.216 | 0.235 |
| E | 2.13 | 2.79 | 0.084 | 0.110 |
| F | 0.08 | 0.18 | 0.003 | 0.007 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| K | 11.05 | – | 0.435 | – |
| L | 6.22 | 6.48 | 0.246 | 0.256 |
| M | 45° NOM | | 45° NOM | |
| N | 3.66 | 4.52 | 0.144 | 0.178 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |

CASE 211-11



MRF453A




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

NOTE:
1. 145A-10, USE 10-32NF-2A STUD.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

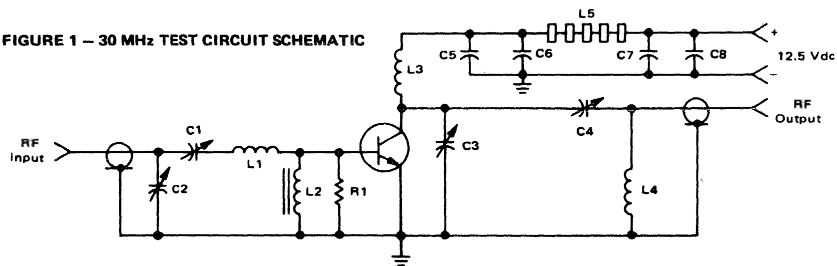
CASE 145A-10

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** (TC = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 250 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $G_{pe}$ | 13 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $\eta$ | 55 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{in}$ | – | 1.66-j.844 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{out}$ | – | 1.73-j.188 | – | Ohms |
| Parallel Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{in}$ | – | 2.09/1030 | – | Ω/pF |
| Parallel Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{out}$ | – | 1.75/330 | – | Ω/pF |

**FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC**




C1, C2, C4 ARCO 469
C3 ARCO 466
C5 1000 pF, UNELCO
C6, C7 0.1 µF Disk Ceramic
C8 1000 µF/15 V Electrolytic
R1 10 Ohm/1 Watt, Carbon

L1 3 Turns, #18 AWG, 5/16" I.D., 5/16" Long
L2 VK200 – 20/4B, FERROXCUBE
L3 12 Turns, #18 AWG Enameled Wire, 1/4" I.D., Close Wound
L4 3 Turns 1/8" O.D. Copper Tubing, 3/8" I.D., 3/4" Long
L5 7 FERRITE Beads, FERROXCUBE #56-590-65/3B

**FIGURE 2 – OUTPUT POWER versus INPUT POWER**

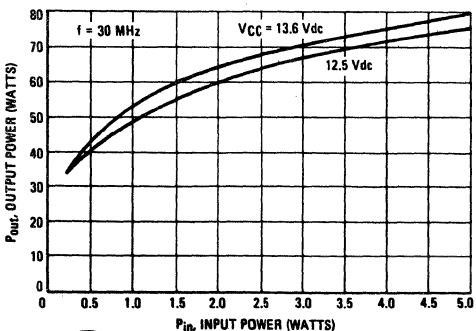
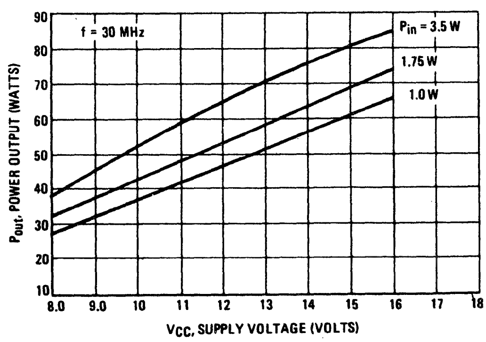



**FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE**




**MOTOROLA Semiconductor Products Inc.**

# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036


# MRF455
# MRF455A

## The RF Line

60 W – 30 MHz
**RF POWER TRANSISTORS**
NPN SILICON

### NPN SILICON RF POWER TRANSISTORS

. . . designed for power amplifier applications in industrial, commercial and amateur radio equipment to 30 MHz.

- Specified 12.5 Volt, 30 MHz Characteristics –
  Output Power = 60 Watts
  Minimum Gain = 13 dB
  Efficiency = 55%

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Emitter Voltage | $V_{CES}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 15 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 175<br>1.0 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | $-65^o$ to $+200^o$ | $^oC$ |

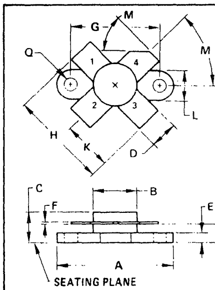
### THERMAL CHARACTERISTICS

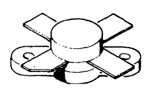
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.0 | $^oC/W$ |

### MATCHING PROCEDURE

In the push-pull circuit configuration it is preferred that the transistors are used as matched pairs to obtain optimum performance.

The matching procedure used by Motorola consists of measuring $h_{FE}$ at the data sheet conditions and color coding the device to predetermined $h_{FE}$ ranges within the normal $h_{FE}$ limits. A color dot is added to the marking on top of the cap. Any two devices with the same color dot can be paired together to form a matched set of units.



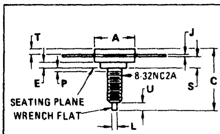



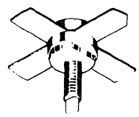
MRF455

STYLE 1
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

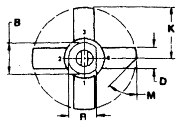
| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0:390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | $40^0$ | $50^0$ | $40^0$ | $50^0$ |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07



MRF455A




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

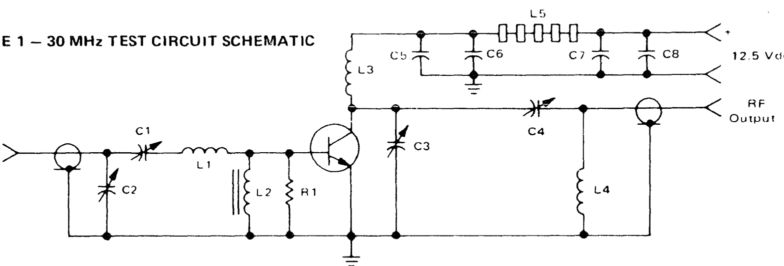
| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18· | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | $45^0$ NOM | | $45^0$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

**ELECTRICAL CHARACTERISTICS** (TC = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 250 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $G_{pe}$ | 13 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $\eta$ | 55 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{in}$ | – | 1.66-j.844 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{out}$ | – | 1.73-j.188 | – | Ohms |
| Parallel Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{in}$ | – | 2.09/1030 | – | Ω/pF |
| Parallel Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 W, f = 30 MHz) | $Z_{out}$ | – | 1.75/330 | – | Ω/pF |

**FIGURE 1 — 30 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1, C2, C4 | ARCO 469 | L1 | 3 Turns, #18 AWG, 5/16" I.D., 5/16" Long |
| C3 | ARCO 466 | L2 | VK200 20/4B, FERROXCUBE |
| C5 | 1000 pF, UNELCO | L3 | 12 Turns, #18 AWG Enameled Wire, 1/4" I.D., Close Wound |
| C6, C7 | 0.1 μF Disk Ceramic | L4 | 3 Turns 1/8" O.D. Copper Tubing, 3/8" I.D., 3/4" Long |
| C8 | 1000 μF/15 V Electrolytic | L5 | 7 FERRITE Beads, FERROXCUBE #56 590-65/3B |
| R1 | 10 Ohm/1 Watt, Carbon | | |

**FIGURE 2 — OUTPUT POWER versus INPUT POWER**

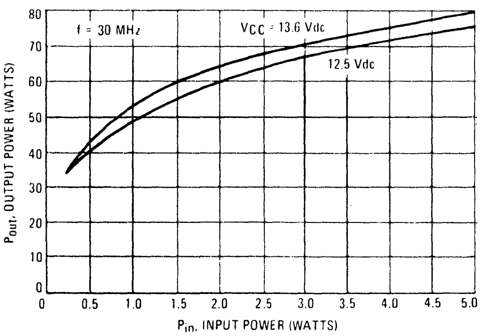
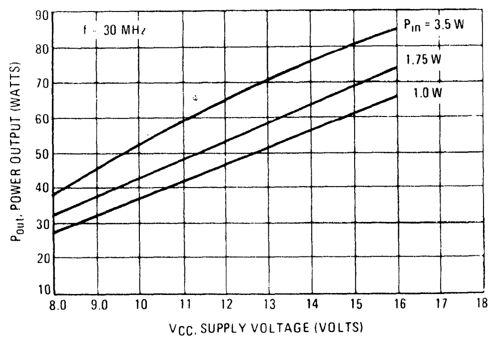



**FIGURE 3 — OUTPUT POWER versus SUPPLY VOLTAGE**



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF475

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

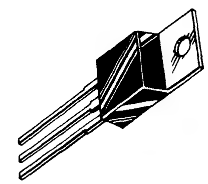
. . . designed primarily for use in single sideband linear amplifier output applications in citizens band and other communications equipment operating to 30 MHz.

- Characterized for Single Sideband and Large-Signal Amplifier Applications Utilizing Low-Level Modulation.
- Specified 13.6 V, 30 MHz Characteristics —
  Output Power = 12 W (PEP)
  Minimum Efficiency = 40% (SSB)
  Output Power = 4.0 W (CW)
  Minimum Efficiency = 50% (CW)
  Minimum Power Gain = 10 dB (PEP & CW)
- Common Collector Characterization

**12 W (PEP) — 4.0 W (CW) — 30 MHz**

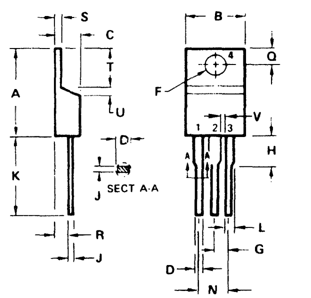
**RF POWER TRANSISTOR**

**NPN SILICON**



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 48 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 50^oC$<br>Derate above $50^oC$ | $P_D$ | 10<br>0.1 | Watts<br>$W/^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +150 | $^oC$ |



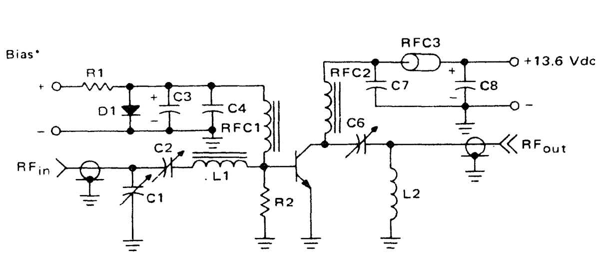

STYLE 1:
PIN 1. BASE
2. COLLECTOR
3. EMITTER
4. COLLECTOR

NOTE:
1. DIM. L & H APPLIES TO ALL LEADS.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 15.11 | 15.75 | 0.595 | 0.620 |
| B | 9.65 | 10.29 | 0.380 | 0.405 |
| C | 4.06 | 4.82 | 0.160 | 0.190 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| F | 3.61 | 3.73 | 0.142 | 0.147 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 2.79 | 3.30 | 0.110 | 0.130 |
| J | 0.36 | 0.56 | 0.014 | 0.022 |
| K | 12.70 | 14.27 | 0.500 | 0.562 |
| L | 1.14 | 1.27 | 0.045 | 0.050 |
| N | 4.83 | 5.33 | 0.190 | 0.210 |
| Q | 2.54 | 3.04 | 0.100 | 0.120 |
| R | 2.04 | 2.79 | 0.080 | 0.110 |
| S | 1.14 | 1.39 | 0.045 | 0.055 |
| T | 5.97 | 6.48 | 0.235 | 0.255 |
| U | 0.76 | 1.27 | 0.030 | 0.050 |
| V | 1.14 | - | 0.045 | - |

**CASE 221A-02**
**TO-220AB**

FIGURE 1 — COMMON-EMITTER TEST CIRCUIT




Adjust for ICQ 20 mA

C1, 2, 6 — ARCO 466 Trimmer Capacitors
C3 — 1000 μF, 3.0 Vdc Electrolytic
C4, 7 — 0.1 μF Disc Ceramics
C8 — 100 μF, 15 Vdc Electrolytic
R1 — 10 Ω, 5.0 Watt Resistor
R2 — 10 Ω, 1.0 Watt Resistor
L1 — 2.2 μH Molded Choke
L2 — 4 Turns #18 AWG Wire, 1/2" I.D., 5/16" Long
RFC1 — 10 μH Molded Choke
RFC2 — 15 Turns #20 AWG Wire on 5.6 kΩ, 1.0 Watt Carbon Resistor
RFC3 — 5 Ferroxcube, #56-590-65/3B, Beads on #18 AWG Wire
D1 — 1N4997

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 48 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 25 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 30 | 60 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 13.6 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 125 | 145 | pF |
| **FUNCTIONAL TESTS (SSB)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, *$P_{out}$ = 12 W, f1 = 30 MHz, f2 = 30.001 MHz, $I_{CQ}$ = 20 mA) | $G_{PE}$ | 10 | 12 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, *$P_{out}$ = 12 W, f1 = 30 MHz, f2 = 30.001 MHz, $I_{CQ}$ = 20 mA) | $\eta$ | 40 | – | – | % |
| Intermodulation Distortion ($V_{CC}$ = 13.6 Vdc, *$P_{out}$ = 12 W, f1 = 30 MHz, f2 = 30.001 MHz, $I_{CQ}$ = 20 mA) | IMD | -30 | – | – | % |
| **FUNCTIONAL TESTS (CW)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 4.0 W, f = 30 MHz) | $G_{PE}$ | 10 | 12 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 4.0 W, f = 30 MHz) | $\eta$ | 50 | – | – | % |
| Percentage Up-Modulation (1) (4.0 W Carrier) | – | – | 100 | – | % |

*PEP

(1) Percentage Up-Modulation is measured in the test circuit (Figure 1) by setting the Carrier Power ($P_c$) to 4.0 Watts with $V_{CC}$ = 13.6 Vdc and noting the power input. Then the Peak Envelope Power (PEP) is noted after doubling the original power input to simulate driver modulation.

$$\text{Percentage Up-Modulation} = \left[\left(\frac{PEP}{P_c}\right) - 1\right] \bullet 100$$

FIGURE 2 — OUTPUT POWER versus INPUT POWER

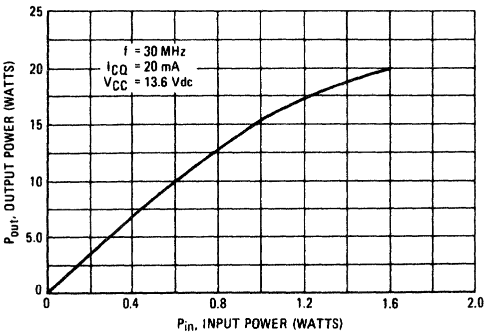



FIGURE 3 — INTERMODULATION DISTORTION versus OUTPUT POWER

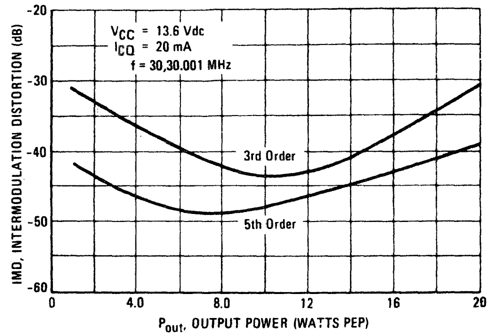



FIGURE 4 — OUTPUT POWER versus SUPPLY VOLTAGE

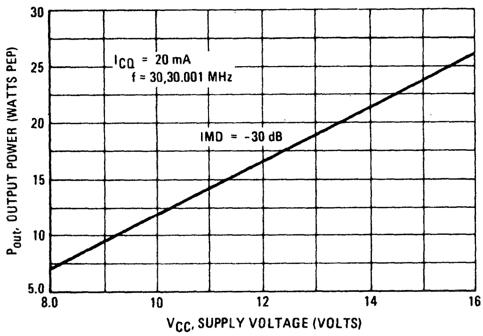



FIGURE 5 — OUTPUT CAPACITANCE versus FREQUENCY

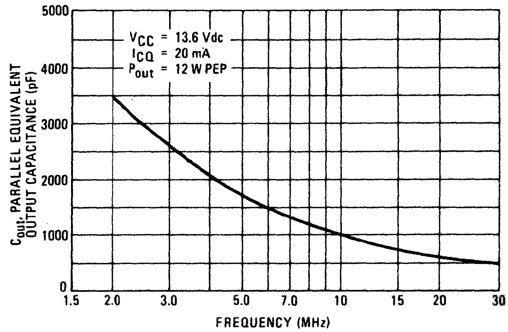



FIGURE 6 — OUTPUT RESISTANCE versus FREQUENCY

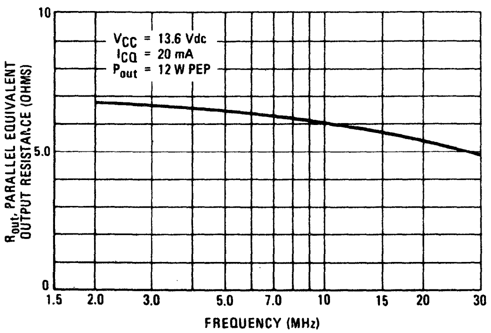



FIGURE 7 — POWER GAIN versus FREQUENCY

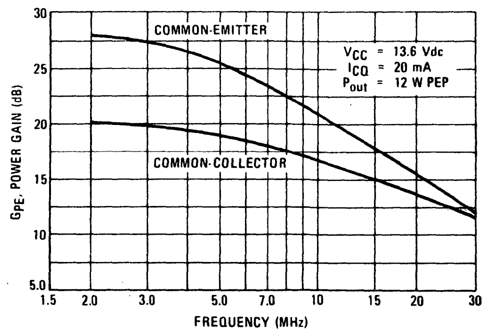


FIGURE 8 – IMPEDANCE COORDINATES – 50-OHM CHARACTERISTICS IMPEDANCE

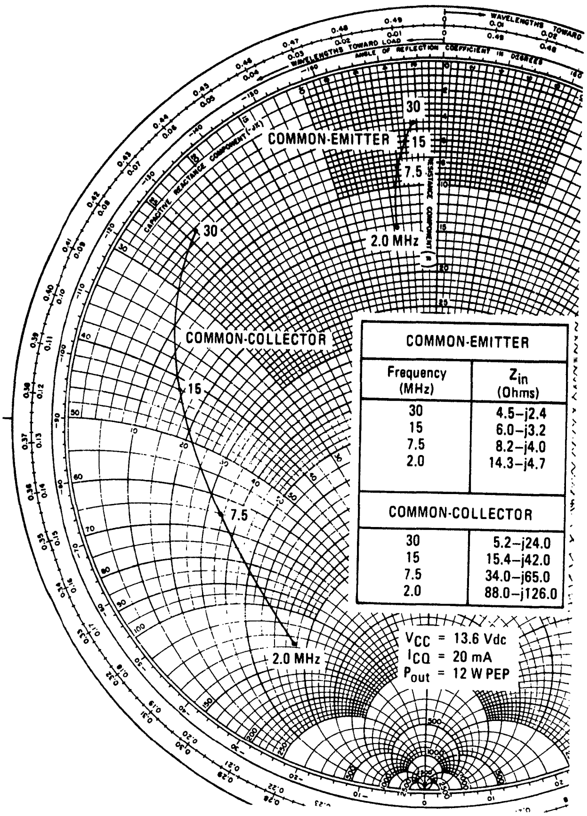
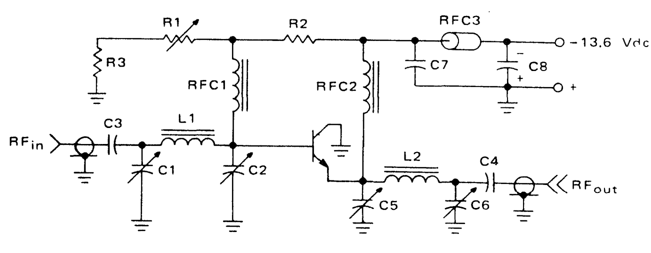



FIGURE 9 – COMMON-COLLECTOR TEST CIRCUIT




| | |
|---|---|
| C1, 5 | – ARCO 466 Trimmer Capacitors |
| C2 | – ARCO 463 Trimmer Capacitor |
| C3, 4, 7 | – 0.1 μF Ceramic Disc |
| C6 | – ARCO 469 Trimmer Capacitor |
| C8 | – 100 μF 15 Vdc Electrolytic |
| R1 | – 250 Ω, 2.0 W Potentiometer |
| R2 | – 5.1 Ω, 1/2 W Resistor |
| R3 | – 51 Ω, 2.0 W Resistor |
| L1 | – 0.33 μH Molded Choke |
| L2 | – 4 Turns #18 AWG Wire, 1/8" I.D., 5/16" Long |
| RFC1 | – 18 μH Molded Choke |
| RFC2 | – 15 Turns #20 AWG Wire on 100 Ω, 1.0 W Carbon Resistor |
| RFC3 | – Ferroxcube, #56-590-65/3B, Beads on #18 AWG Wire |

**MOTOROLA**
**Semiconductors**
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# MRF476

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

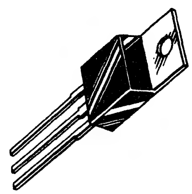
. . . designed primarily for use in single sideband linear amplifier output applications in citizens band and other communications equipment operating to 50 MHz.

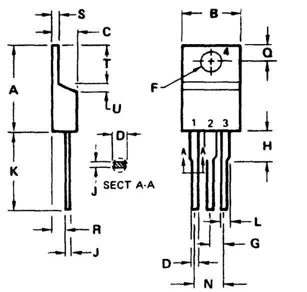
- Characterized for Single Sideband and Large-Signal Amplifier Applications Utilizing Low-Level Modulation
- Specified 12.5 V, 30 MHz Characteristics –
  Output Power = 3.0 W (PEP)
  Minimum Efficiency = 40% (SSB)
  Output Power = 3.0 W (CW)
  Minimum Power Gain = 15 dB (PEP)
- Common-Emitter Characterization

**3.0 W (PEP)–3.0 W (CW) – 30 MHz**

**RF POWER TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. BASE
2. COLLECTOR
3. EMITTER
4. COLLECTOR

NOTE:
1. DIM. L & H APPLIES TO ALL LEADS.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 15.11 | 15.75 | 0.595 | 0.620 |
| B | 9.65 | 10.29 | 0.380 | 0.405 |
| C | 4.06 | 4.82 | 0.160 | 0.190 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| F | 3.61 | 3.73 | 0.142 | 0.147 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 2.79 | 3.30 | 0.110 | 0.130 |
| J | 0.36 | 0.56 | 0.014 | 0.022 |
| K | 12.70 | 14.27 | 0.500 | 0.562 |
| L | 1.14 | 1.27 | 0.045 | 0.050 |
| N | 4.83 | 5.33 | 0.190 | 0.210 |
| Q | 2.54 | 3.04 | 0.100 | 0.120 |
| R | 2.04 | 2.79 | 0.080 | 0.110 |
| S | 1.14 | 1.39 | 0.045 | 0.055 |
| T | 5.97 | 6.48 | 0.235 | 0.255 |
| U | 0.76 | 1.27 | 0.030 | 0.050 |

**CASE 221A-02**
**TO-220AB**

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_A$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 10<br>57.2 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to + 150 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

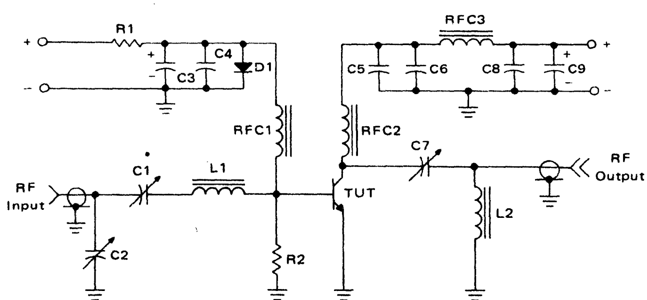
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 17.5 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISITCS** | | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 50 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 25 | 35 | pF |
| **FUNCTIONAL TESTS (SSB)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.0 W (PEP) f1 = 30 MHz, f2 = 30.001 MHz, ICQ = 20 mA) | $G_{PE}$ | 15 | 18 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.0 W (PEP) f1 = 30 MHz, f2 = 30.001 MHz, ICQ = 20 mA) | $\eta$ | 40 | – | – | % |
| Intermodulation Distortion ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.0 W (PEP) f1 = 30 MHz, f2 = 30.001 MHz, ICQ = 20 mA | IMD | -30 | -35 | – | dB |
| **50 MHz PERFORMANCE** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.0 W, f = 50 MHz) | $G_{PE}$ | – | 15 | – | dB |

**FIGURE 1 – 30 MHz TEST CIRCUIT SCHEMATIC**




C2 – Arco 466 Trimmer
C1, C7 – Arco 469 Trimmer
C3 – 500 μF, 3.0 V Electrolytic
C4, C5, C8 – 0.1 μF Erie Redcap
C6 – 1000 pF UNELCO
C9 – 100 μF, 15 V Electrolytic

R1 – 33 Ω 5 W Wire Wound
R2 – 50 Ω 1/2 W Carbon

L1 – 0.22 μH Molded Choke
L2 – 5 Turns #18 Enameled Wire, 1/4" ID

RFC1 – 10 μH Molded Choke
RFC2 – 1.9 μH Molded Choke (Ohmite Z-144)
RFC3 – 6 Ferroxcube Beads on #18 AWG Wire

D1 – MR751

Board – G10, 2-sided 2 oz. Copper Clad

Connectors – Type N

FIGURE 2 – POWER GAIN versus FREQUENCY

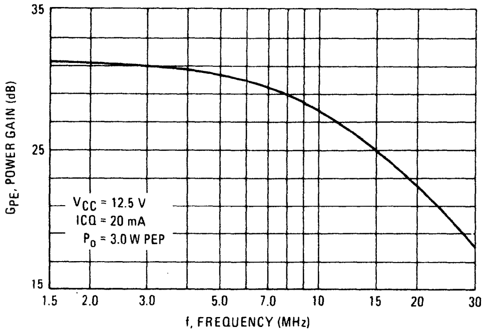



FIGURE 3 – OUTPUT POWER versus INPUT POWER

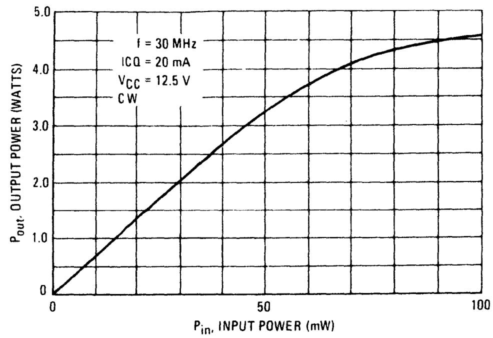



FIGURE 4 – OUTPUT POWER versus INPUT POWER

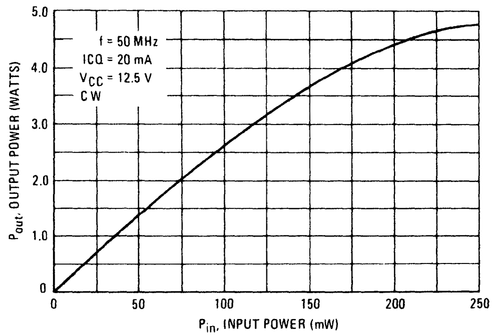



FIGURE 5 – OUTPUT POWER versus SUPPLY VOLTAGE

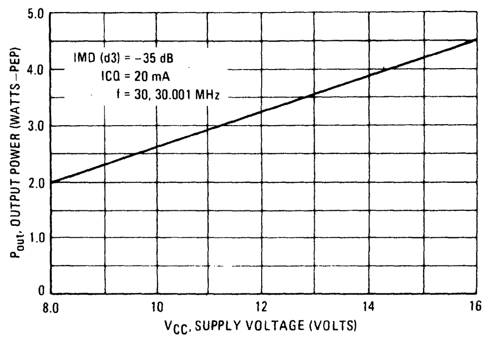



FIGURE 6 – INTERMODULATION DISTORTION versus OUTPUT POWER

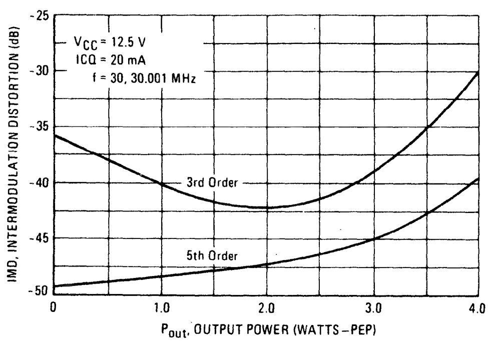



FIGURE 7 – OUTPUT CAPACITANCE versus FREQUENCY

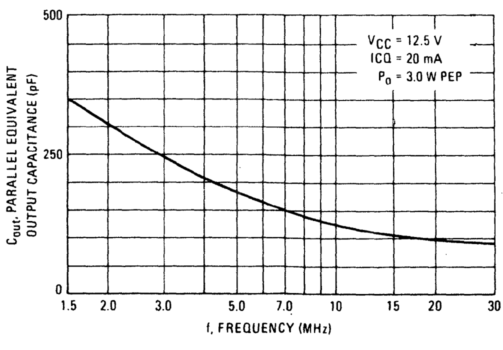


FIGURE 8 – OUTPUT RESISTANCE versus FREQUENCY

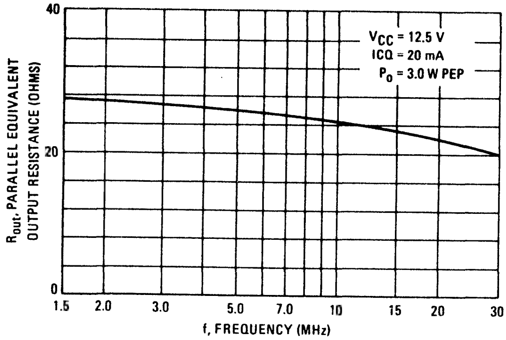
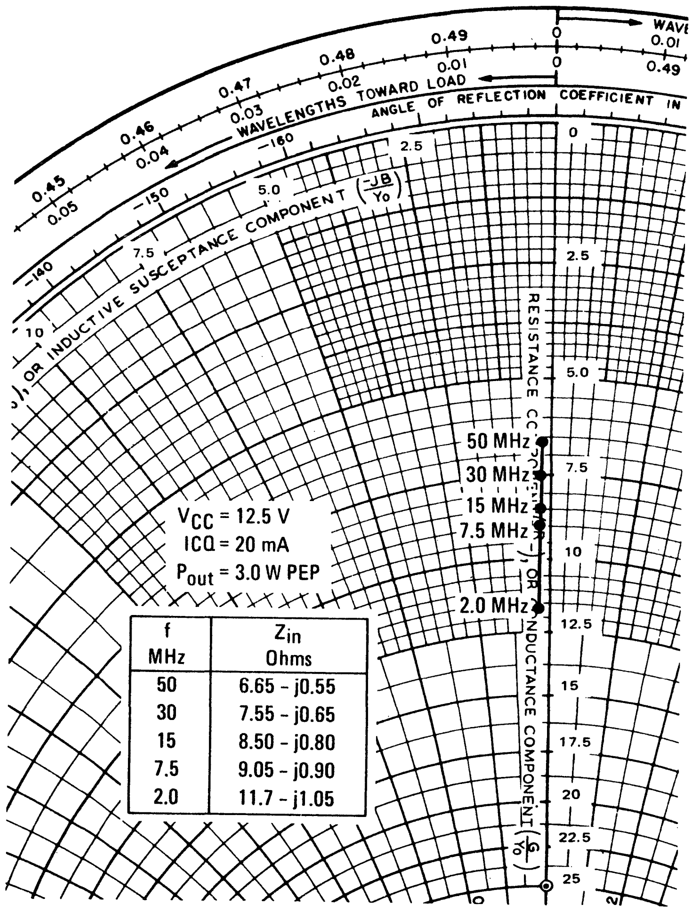



FIGURE 9 – SERIES EQUIVALENT INPUT IMPEDANCE




| f MHz | $Z_{in}$ Ohms |
|---|---|
| 50 | 6.65 - j0.55 |
| 30 | 7.55 - j0.65 |
| 15 | 8.50 - j0.80 |
| 7.5 | 9.05 - j0.90 |
| 2.0 | 11.7 - j1.05 |

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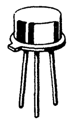
# MRF8003

## The RF Line

**0.5 W – 27 MHz**
**HIGH FREQUENCY TRANSISTOR**
**NPN SILICON**



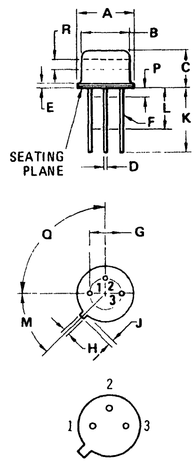
### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for 12.5 Volt amplifier applications in 27 MHz Citizen-Band applications. Suitable for use as a driver for the MRF8004.

Specified 12.5 Volt, 27 MHz Characteristics –
- Output Power = 0.5 Watt
- Minimum Gain = 10 dB
- Efficiency = 50%

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector - Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector - Base Voltage | $V_{CBO}$ | 50 | Vdc |
| Emitter - Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current - Continuous | $I_C$ | 0.5 | Adc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 1.0<br>5.7 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |




STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

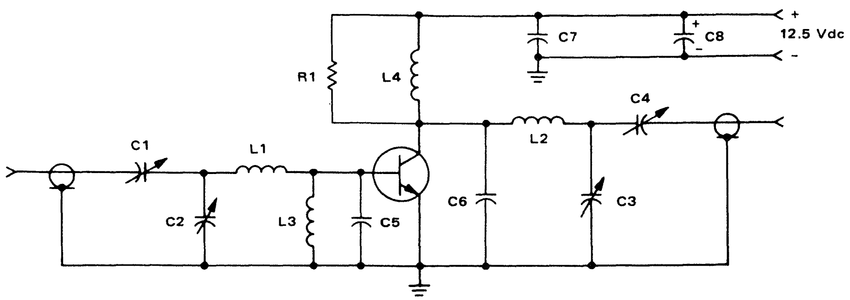
All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 0.1 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 50 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 12 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 15 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 27 MHz) | $G_{PE}$ | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 27 MHz) | $\eta$ | | 50 | % |

**FIGURE 1 – 27 MHz TEST CIRCUIT SCHEMATIC**




| | |
|---|---|
| C1, C2, C3, C4 | 9.0-180 pF ARCO 463 or equivalent |
| C5 | 25 pF UNDERWOOD |
| C6 | 100 pF UNDERWOOD |
| C7 | 1000 pF UNDERWOOD |
| C8 | 10 μF ELECTROLYTIC |
| L1, L2 | 0.47 μH Molded Coil |
| L3 | VK 200-20/4B RFC |
| L4 | 16 Turns No. 26 Wire Closewound on R1 |
| R1 | 390 Ω, 2 W |

**MOTOROLA Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF8004

## The RF Line

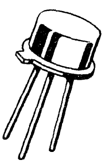
### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for use in large-signal output amplifier stages. Intended for use in Citizen-Band communications equipment operating to 30 MHz. High breakdown voltages allow a high percentage of up-modulation in AM circuits.

- Specified 12.5 V, 27 MHz Characteristics –
  Power Output = 3.5 W
  Power Gain = 10 dB
  Efficiency = 70% Typical

**3.5 W – 27 MHz RF POWER TRANSISTOR**

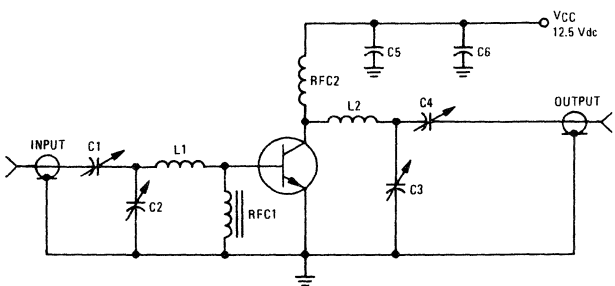
**NPN SILICON**



### MAXIMUM RATINGS

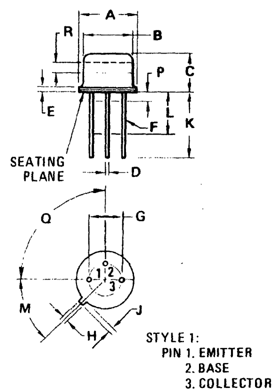
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

FIGURE 1 – 27 MHz TEST CIRCUIT




C1, C2 9.0-180 pF ARCO 463 or Equivalent
C3, C4 5.0-80 pF ARCO 462 or Equivalent
C5 0.02 µF Ceramic Disc
C6 0.1 µF Ceramic Disc
RFC1 4 Turns #30 Enameled Wire Wound on Ferroxcube Bead Type 56-590-65/3B
RFC2 26 Turns #22 Enameled Wire (2 Layers – 13 Turns Each Layer) ¼" Inner Diameter
L1 0.22 µH Molded Choke
L2 0.68 µH Molded Choke

(1) This device is designed for RF operation. The total device dissipation rating applies only when the device is operated as an RF amplifier.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.01 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 400 mAdc, $V_{CE}$ = 2.0 Vdc) | $h_{FE}$ | 10 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 35 | 70 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (See Figure 1) ($P_{out}$ = 3.5 W, $V_{CC}$ = 12.5 Vdc, f = 27 MHz) | $G_{PE}$ | 10 | – | – | dB |
| Collector Efficiency (2) (See Figure 1) ($P_{out}$ = 3.5 W, $V_{CC}$ = 12.5 Vdc, f = 27 MHz) | $\eta$ | 62.5 | 70 | – | % |
| Percentage Up-Modulation (1) (See Figure 1) (f = 27 MHz) | – | – | 85 | – | % |
| Parallel Equivalent Input Resistance ($P_{out}$ = 3.5 W, $V_{CC}$ = 12.5 Vdc, f = 27 MHz) | $R_{in}$ | – | 21 | – | Ohms |
| Parallel Equivalent Input Capacitance ($P_{out}$ = 3.5 W, $V_{CC}$ = 12.5 Vdc, f = 27 MHz) | $C_{in}$ | – | 900 | – | pF |
| Parallel Equivalent Output Capacitance ($P_{out}$ = 3.5 W, $V_{CC}$ = 12.5 Vdc, f = 27 MHz) | $C_{out}$ | – | 200 | – | pF |

(1) Percentage Up-Modulation is measured in the test circuit (Figure 1) by setting the Carrier Power ($P_c$) to 3.5 Watts with $V_{CC}$ = 12.5 Vdc and noting the power input. Then the Peak Envelope Power (PEP) is noted after doubling the original power input to simulate driver modulation (at a 25% duty cycle for thermal considerations) and raising the $V_{CC}$ to 25 Vdc (to simulate the modulating voltage). Percentage Up-Modulation is then determined by the relation:

$$\text{Percentage Up-Modulation} = \left[\left(\frac{PEP}{P_c}\right)^{1/2} - 1\right] \bullet 100$$

(2) $\eta = \dfrac{R_F\ P_{out}}{(V_{CC})\ (I_C)} \bullet 100$

**FIGURE 2 – CIRCUIT TUNED AT 25 V, 25% DUTY CYCLE, $P_{out}$ = 15 W PEAK**

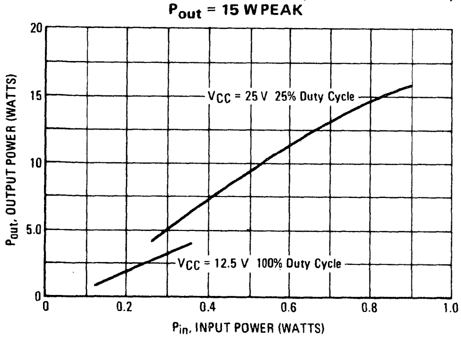
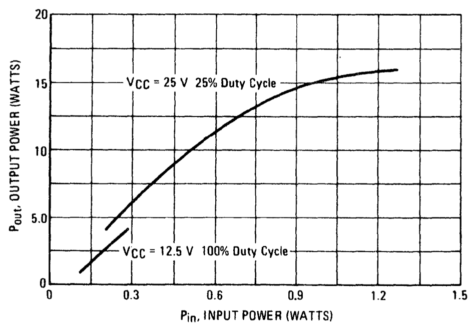
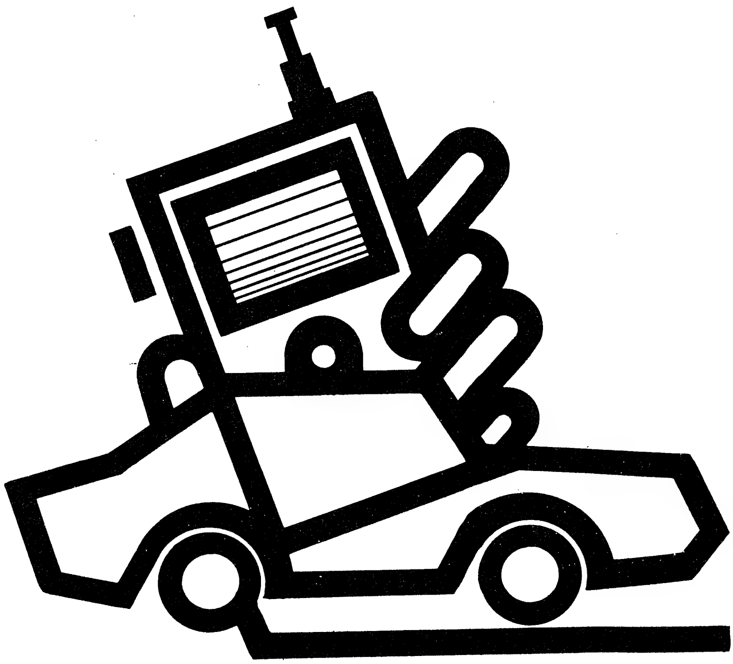



**FIGURE 3 – CIRCUIT TUNED AT 12.5 V, $P_{out}$ = 4 W**



# 27-50 MHz, 12.5 Vdc

# CHAPTER 6



MOTOROLA
Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5847

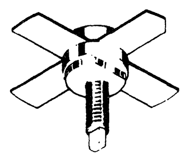
## The RF Line

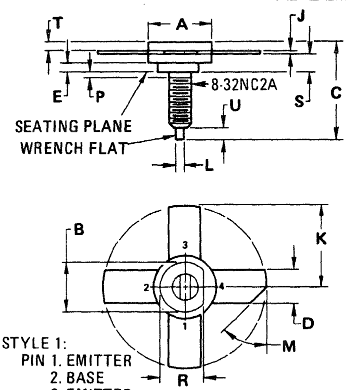
7.0 W – 50 MHz
**RF POWER TRANSISTOR**
**NPN SILICON**

## NPN SILICON RF POWER TRANSISTORS

. . . designed primarily for use in large-signal amplifier driver and pre-driver stages, these devices are intended for use in industrial communications equipment operating at frequencies to 80 MHz.

- Specified 12.5 Volt, 50 MHz Characteristics –
  Output Power = 8.0 W
  Minimum Gain = 10 dB
  Efficiency = 50%






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 20<br>114 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.

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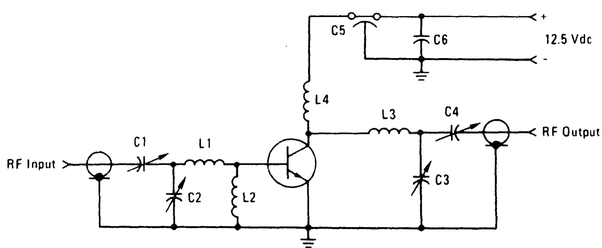
*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage(1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage (1) ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 125°C) | $I_{CES}$ | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 90 | pF |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 8.0 W, f = 50 MHz) | $G_{PE}$ | 10 | – | dB |
| Output Power ($V_{CC}$ = 12.5 Vdc, $P_{in}$ = 800 mW, f = 50 MHz) | $P_{out}$ | 8.0 | – | Watts |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 8.0 W, f = 50 MHz) | $\eta$ | 50 | – | % |

*Indicates JEDEC Registered Data
(1) Pulsed thru a 25 mH inductor.

6

FIGURE 1 – 50 MHz TEST CIRCUIT




| | |
|---|---|
| C1, C3, C4 | 25-280 pF, Arco 464 or Equivalent |
| C2 | 80-480 pF, Arco 466 or Equivalent |
| C5 | 1000 pF Feedthru |
| C6 | 0.1 μF, 75 Vdc |
| L1 | 1 Turn, #14 AWG ½" I.D. |
| L2 | Large Ferrite Bead, 2½ Turns |
| L3 | 3 Turns, #14 AWG, ½" I.D. |
| L4 | 20 Turns, #18 AWG NYCLAD Wire, 2 Layers (10 Turns Per Layer) ¼" I.D. |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

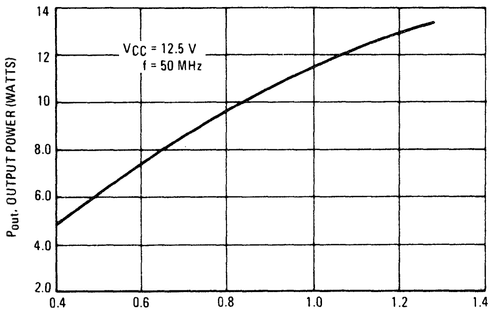



FIGURE 3 – OUTPUT POWER versus FREQUENCY

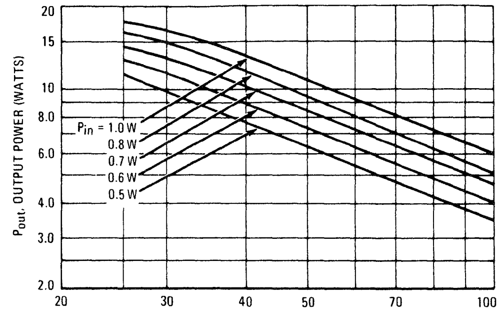



FIGURE 4 – POWER DISSIPATION DERATING

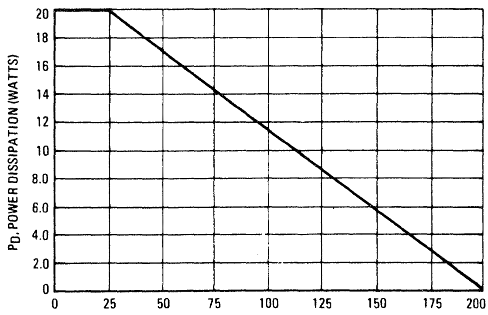



FIGURE 5 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

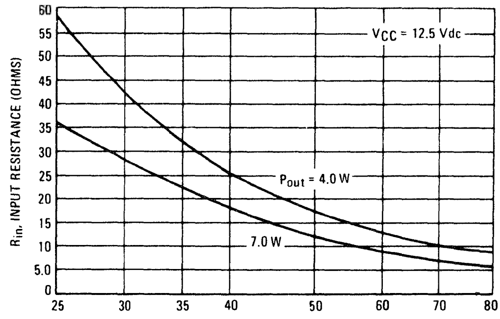



FIGURE 6 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

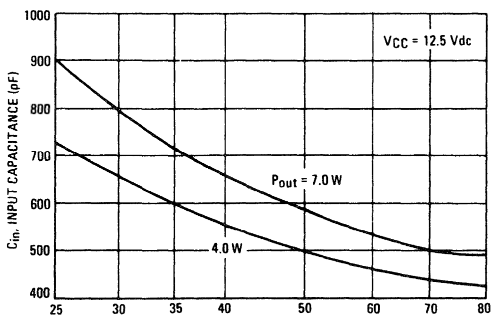
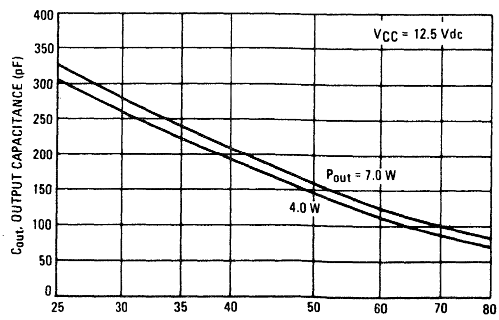



FIGURE 7 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY



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BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5848

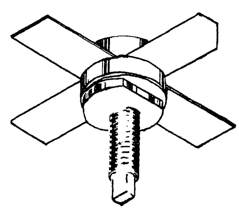
## The RF Line

### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for use in large-signal amplifier driver and output stages, the 2N5848 is intended for use in industrial communications equipment operating at frequencies to 80 MHz.

- Optimized for Operation from a 12.5 Volt Supply
- 20 Watts (Min) RF Power Output at 50 MHz
- Balanced Emitter Construction for Burn Out Protection

20 W-50 MHz
RF POWER
TRANSISTOR
NPN SILICON

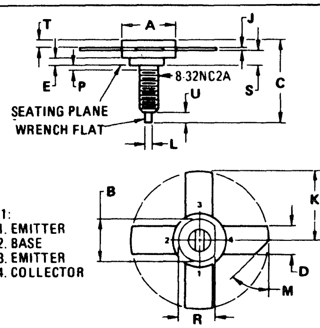


6

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 24 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 48 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 3.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 50<br>285 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |
| Stud Torque (1) | – | 6.5 | in-lbs. |

*Indicates JEDEC Registered Data.
(1) For repeated assembly use 5 in-lbs.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage(1) ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 24 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage(1) ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 48 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_A$ = +125°C) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.2 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 3.0 | 15 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 100 | 125 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, $I_C$ = 3.2 Adc, f = 50 MHz) | $G_{PE}$ | 8.0 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, $I_C$ = 3.2 Adc, f = 50 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.
(1)Pulsed thru a 25 mH Inductor.

FIGURE 1 – 50 MHz POWER GAIN TEST CIRCUIT

| | |
|---|---|
| C1, C8, C9 | 20-300 pF ARCO 464 Capacitor |
| C2 | 40-600 pF ARCO 466 Capacitor |
| C3, C4 | 100 pF UNDERWOOD |
| C5 | 0.001 µF MICA Dipped Capacitor |
| C6 | 20 µF Capacitor |
| C7 | 0.001 µF UNDERWOOD Capacitor |
| L1 | 3/4 Turns #16 AWG, 3/8" ID, 1-1/4" Long |
| L2 | 2 Turns #18 AWG, 3/8" ID, 1-1/4" Long |
| L3 | 13 Turns #16 AWG, 1/4" ID |

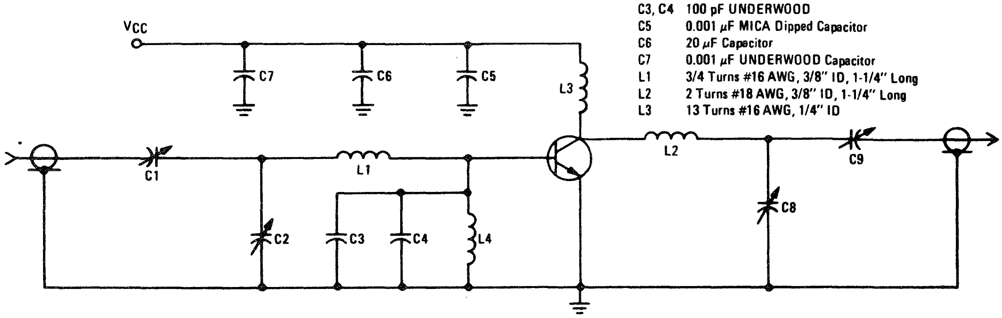


FIGURE 2 – OUTPUT POWER versus INPUT POWER

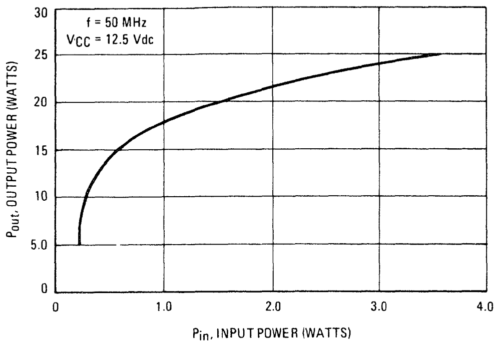



FIGURE 3 – OUTPUT POWER versus FREQUENCY

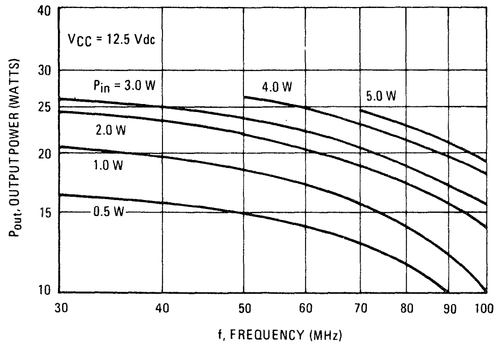



FIGURE 4 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

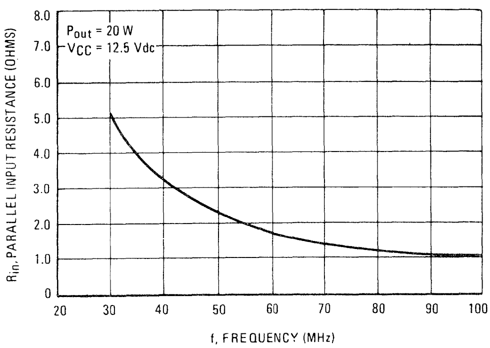



FIGURE 5 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

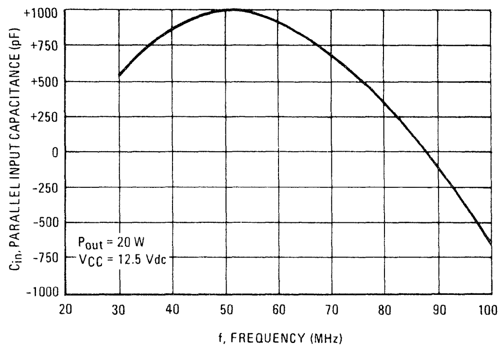



FIGURE 6 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

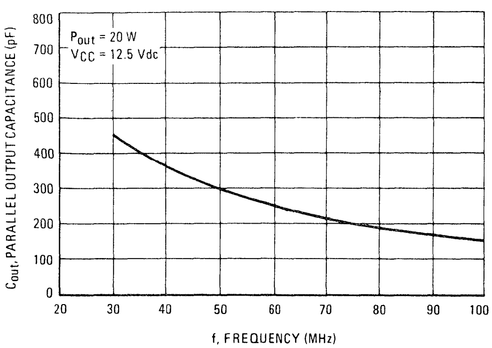
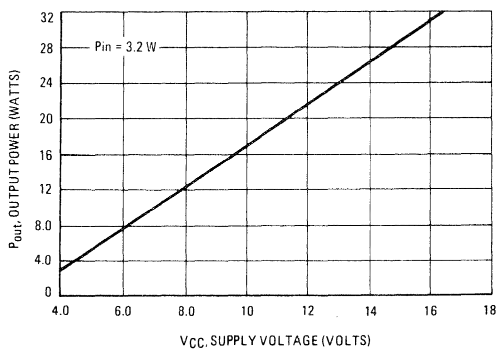
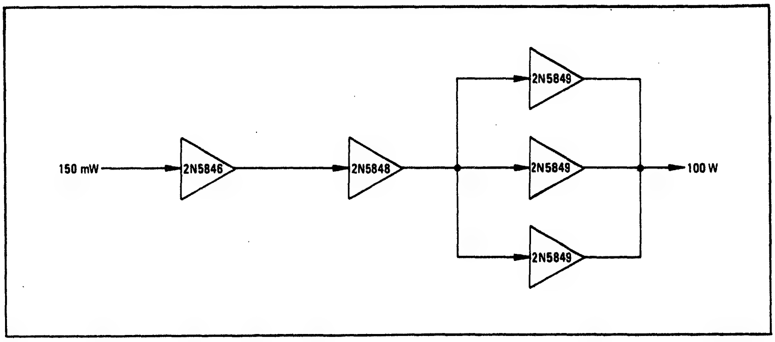



FIGURE 7 – OUTPUT POWER versus SUPPLY VOLTAGE



LOW-BAND FM (25-50 MHz) 12.5 Vdc, 100 WATT AMPLIFIER



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5849

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

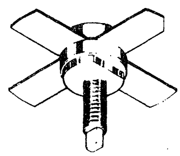
**40 W–50 MHz**

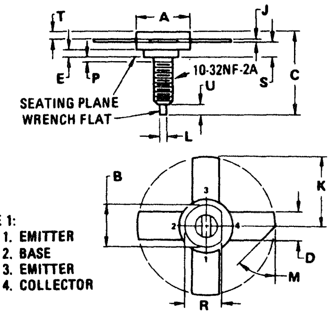
**RF POWER TRANSISTOR**

**NPN SILICON**

... . designed primarily for use in large-signal amplifier output stages, the 2N5849 is intended for use in industrial communications equipment operating at frequencies to 80 MHz.

- Specified 12.5 Volt, 50 MHz Characteristics –
  Output Power = 40 Watts
  Minimum Gain = 7.5 dB
  Efficiency = 50%






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | $45^{0}$ NOM | | $45^{0}$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-10

*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 24 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 48 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 7.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 100<br>571 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

*Indicates JEDEC Registered Data.

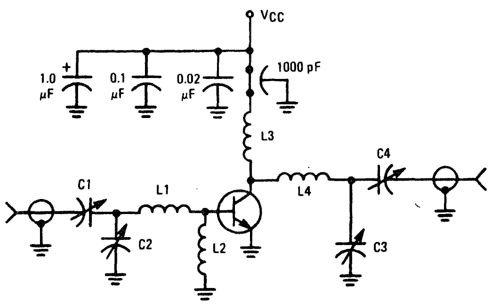
This device is designed for RF operation. The total device dissipation rating applies only when the device is operated as an RF amplifier.

*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage(1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 24 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage(1) ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 48 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_A$ = +125°C) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.4 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 3.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 180 | 230 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 50 MHz) | $G_{PE}$ | 7.5 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 50 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.
(1)Pulsed thru a 25 mH Inductor.

FIGURE 1 – 50 MHz POWER GAIN TEST CIRCUIT




C1 25-280 pF, Arco 464 or Equivalent
C2 80-480 pF, Arco 466 or Equivalent
C3 0-75 pF, Hammarlund MAPC 75 or Equivalent
C4 0-50 pF, Hammarlund MAPC 50 or Equivalent
L1 1 Turn #14 AWG 5/16" I.D.
L2 2-1/2 Turns #22 AWG on 3/8" Ferrite Bead
L3 18 Turns #18 AWG 3/8" I.D. 2 Layers, 9 Turns Each
L4 4 Turns #14 AWG 7/16" I.D. 7/16" Long

FIGURE 2 – POWER OUTPUT versus POWER INPUT

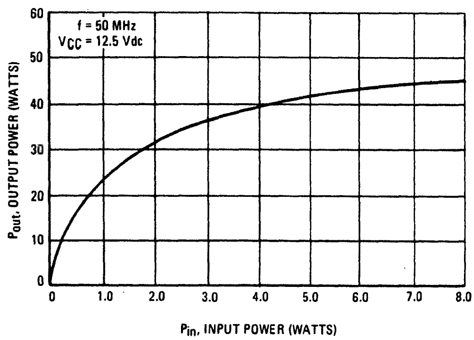



FIGURE 3 – POWER OUTPUT versus FREQUENCY

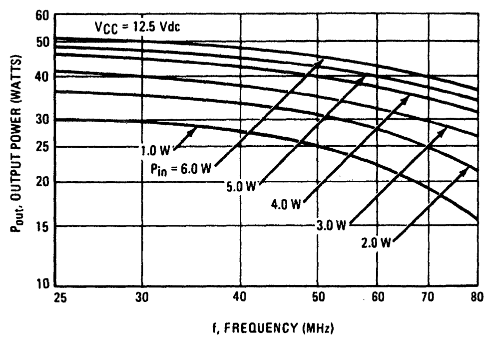



FIGURE 4 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

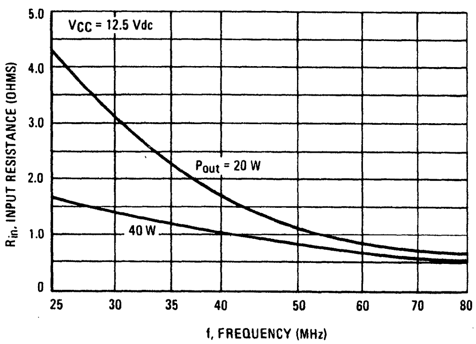



FIGURE 5 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

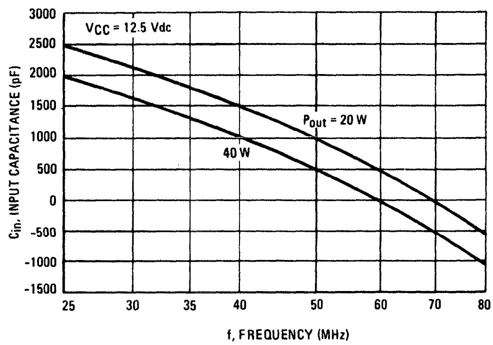



FIGURE 6 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

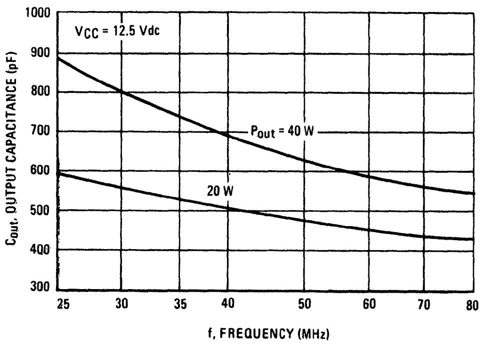
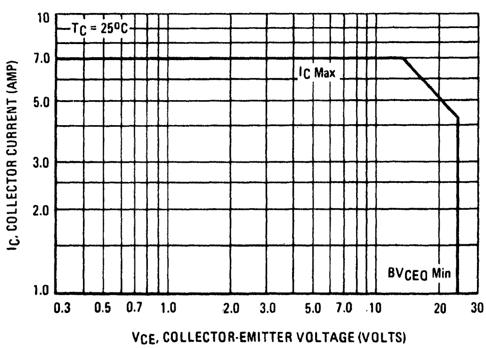
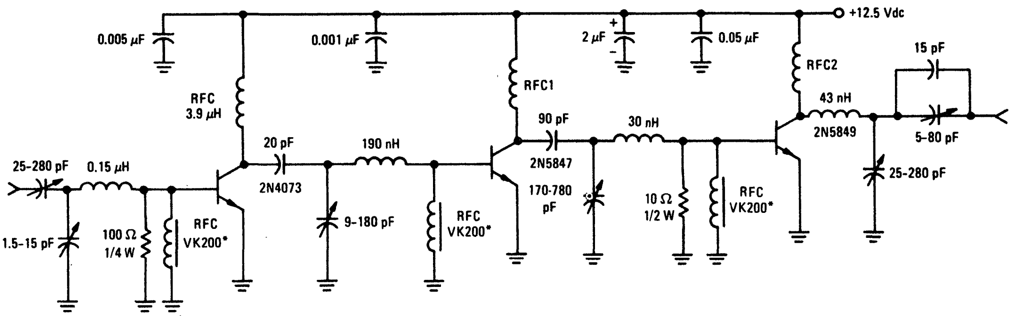



FIGURE 7 – DC SAFE OPERATING AREA



## 40 WATT, 50 MHz TRANSMITTER SCHEMATIC




$P_o$ = 40 W
$P_{in}$ = 20 mW
Overall Gain = 33 dB
Overall Efficiency = 59.2%

*Ferroxcube Part Number
RFC1 – 20 Turns #18 AWG, 3/16" I.D., 2 Layers, 10 Turns Each, Close Wound.
RFC2 – 18 Turns, #18 AWG, 3/16" I.D., 2 Layers, 9 Turns Each, Close Wound.

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# MRF402

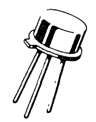
## The RF Line

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt low band power amplifier applications required in industrial and commercial equipment.

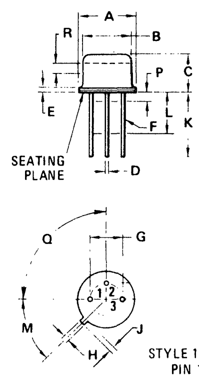
- Specified 12.5 Volt, 50 MHz Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 10 dB
  Efficiency = 50%

**1.0 W – 50 MHz**
**RF POWER TRANSISTOR**
**NPN SILICON**



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector - Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector - Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter - Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current - Continuous | $I_C$ | 0.5 | Adc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 1.0<br>5.62 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |




STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | $45^o$ NOM | | $45^o$ NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | $90^o$ NOM | | $90^o$ NOM | |
| R | 2.54 | – | 0.100 | – |

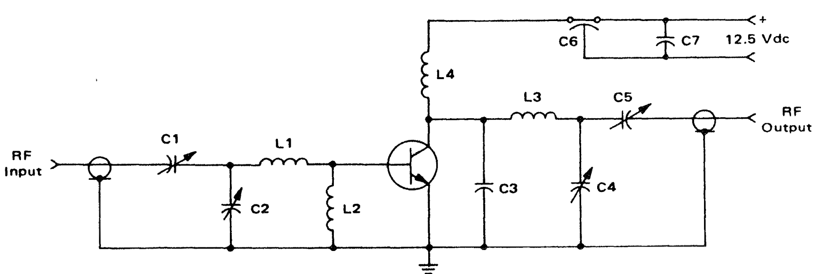
All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

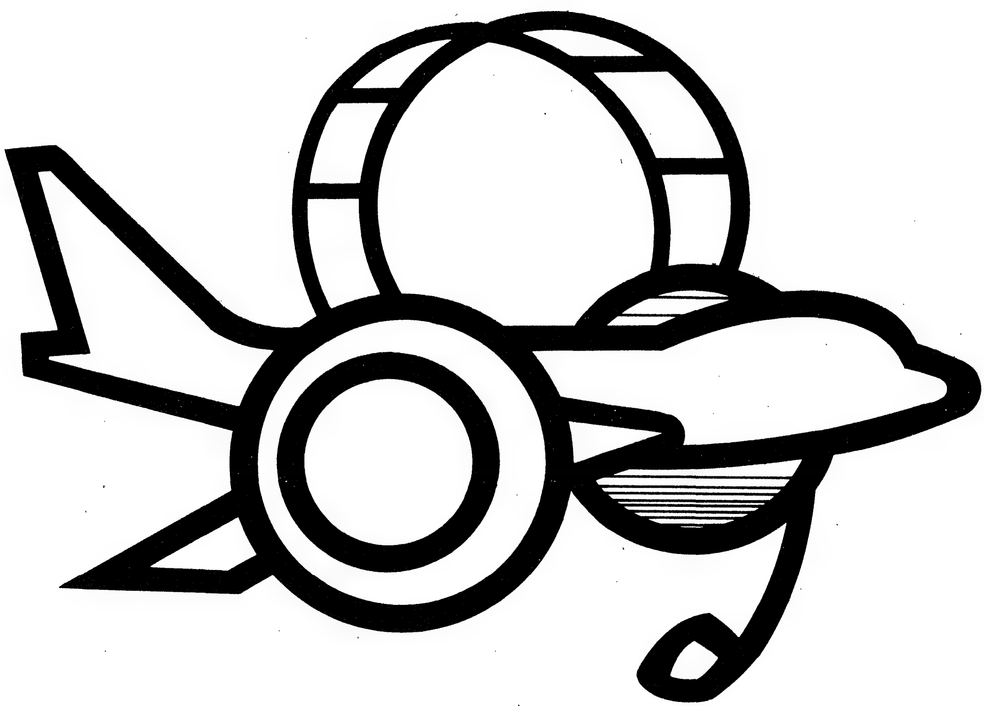
| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.25 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 25 | pF |
| **FUNCTIONAL TESTS** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, $I_C$ (max) = 160 mAdc, f = 50 MHz) | $G_{PE}$ | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, $I_C$ (max) = 160 mAdc, f = 50 MHz) | $\eta$ | 50 | – | % |

FIGURE 1 – 50 MHz TEST CIRCUIT SCHEMATIC




C1,C2,C5 – 25-280 pF, ARCO 464 or equiv.
C3 – 40 pF, 500 Vdc UNELCO
C4 – 9.0-180 pF ARCO 463 or equiv.
C6 – 1000 pF feedthru
C7 – 0.1 µF, 75 Vdc

L1 – 2 Turns No. 18 AWG, 3/8" I.D.
L2 – 2 1/2 Turns, Small Ferrite Bead
L3 – 5 Turns No. 18 AWG, 3/8" I.D.
L4 – 1.0 µH RF Choke



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# 2N3553

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTOR

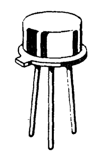
. . . designed for amplifier and oscillator applications in military and industrial equipment. Suitable for use as output, driver or pre-driver stages in VHF equipment.

- Specified 175 MHz, 28 Vdc Characteristics –
  Output Power = 2.5 Watts
  Minimum Gain = 10 dB
  Efficiency = 50%

**2.5 W – 175 MHz**

**HIGH FREQUENCY TRANSISTOR**

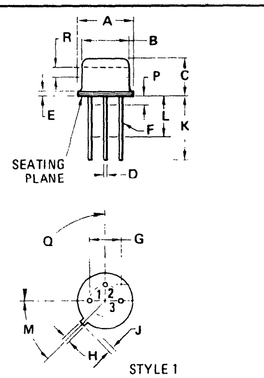
**NPN SILICON**



*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 40 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 7.0<br>40 | Watts<br>$mW/^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

*Indicates JEDEC Registered Data.

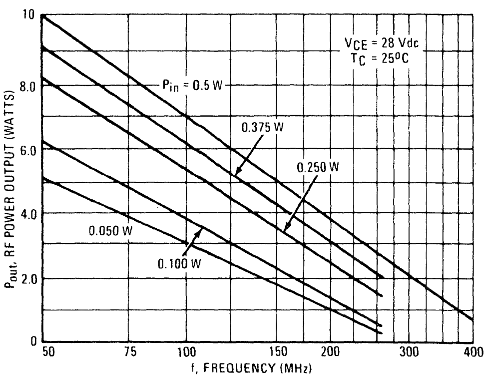



| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | $45^o$ NOM | | $45^o$ NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | $90^o$ NOM | | $90^o$ NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

FIGURE 1 – OUTPUT POWER versus FREQUENCY

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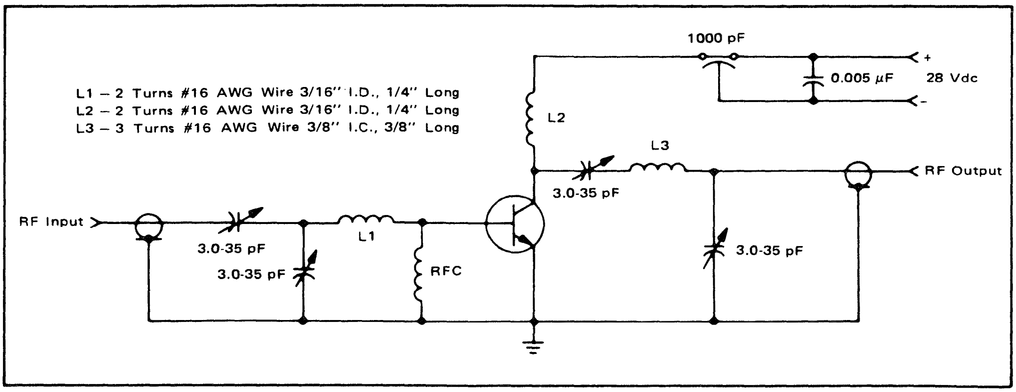
***ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Sustaining Voltage (1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 30 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 0.1 | mAdc |
| Collector Cutoff Current ($V_{CE}$ = 30 Vdc, $V_{BE(off)}$ = 1.5 Vdc, $T_C$ = 200°C) ($V_{CE}$ = 65 Vdc, $V_{BE(off)}$ = 1.5 Vdc) | $I_{CEX}$ | –<br>– | –<br>– | 5.0<br>1.0 | mAdc |
| Emitter Cutoff Current ($V_{BE}$ = 4.0 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 250 mAdc, $I_B$ = 50 mAdc) | $V_{CE(sat)}$ | – | – | 1.0 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 100 mAdc, $V_{CE}$ = 28 Vdc, f = 100 MHz) | $f_T$ | – | 500 | – | MHz |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 100 kHz) | $C_{ob}$ | – | 8.0 | 10 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Power Input ($V_{CE}$ = 28 Vdc, $P_{out}$ = 2.5 Watts, f = 175 MHz) | $P_{in}$ | – | – | 0.25 | Watt |
| Common-Emitter Amplifier Power Gain ($V_{CE}$ = 28 Vdc, $P_{out}$ = 2.5 Watts, f = 175 MHz) | $G_{pe}$ | 10 | – | – | dB |
| Collector Efficiency ($V_{CE}$ = 28 Vdc, $P_{out}$ = 2.5 Watts, f = 175 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data
(1) Pulsed thru a 25 mH inductor.

FIGURE 2 — 175 MHz TEST CIRCUIT SCHEMATIC



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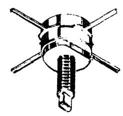
# 2N5641

## The RF Line

7.0 W – 175 MHz

RF POWER
TRANSISTOR

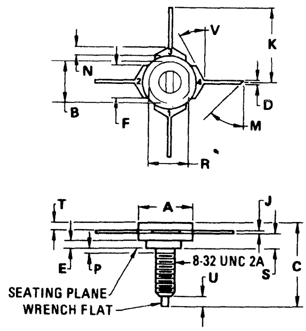
NPN SILICON



## NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal amplifier stages in the 125-175 MHz frequency range.

- Specified 28 Volt, 175 MHz Characteristics –
  Output Power = 7.0 Watts
  Minimum Gain = 8.4 dB
  Efficiency = 60%
- Characterized from 125 to 175 MHz
- Includes Series Equivalent Impedances




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

NOTE:
1. DIM "N" IS FROM DIA "A" TO ANGLE "V"

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 1.78 | – | 0.070 | – |
| F | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| M | 45° NOM | | 45° NOM | |
| N | 1.27 | 1.52 | 0.050 | 0.060 |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |
| V | 10° | 20° | 10° | 20° |

CASE 144B-05

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 15<br>86 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

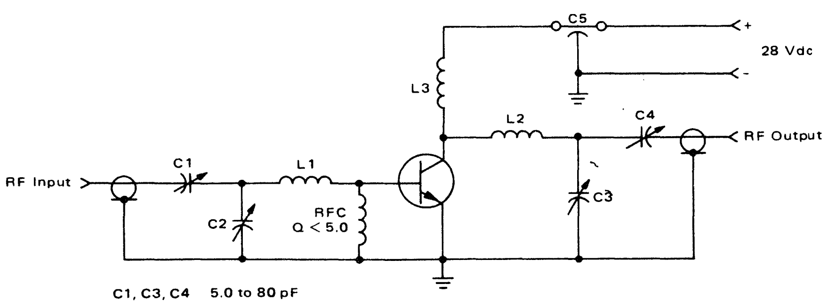
*Indicates JEDEC Registered Data.

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 8.5 | 15 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 7.0 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $G_{PE}$ | 8.4 | 12.5 | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 7.0 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |

Note 1: Pulsed through 25 mH inductor.
*Indicates JEDEC Registered Data.

FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC




| | |
|---|---|
| C1, C3, C4 | 5.0 to 80 pF |
| C2 | 9.0 - 180 pF |
| C5 | 0.1 μF |
| L1 | 1-1/4 Straight #14 AWG |
| L2 | 3 Turns #16 AWG, 14" I.D. |
| L3 | 0.22 μH |

FIGURE 2 – OUTPUT POWER versus FREQUENCY

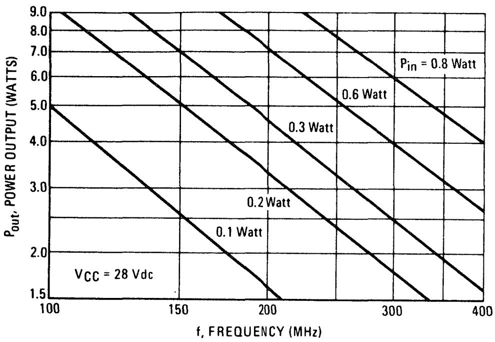



FIGURE 3 – OUTPUT POWER versus FREQUENCY

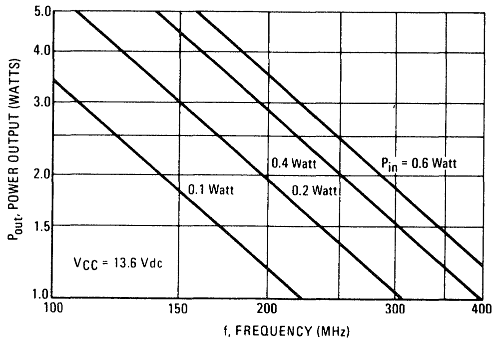
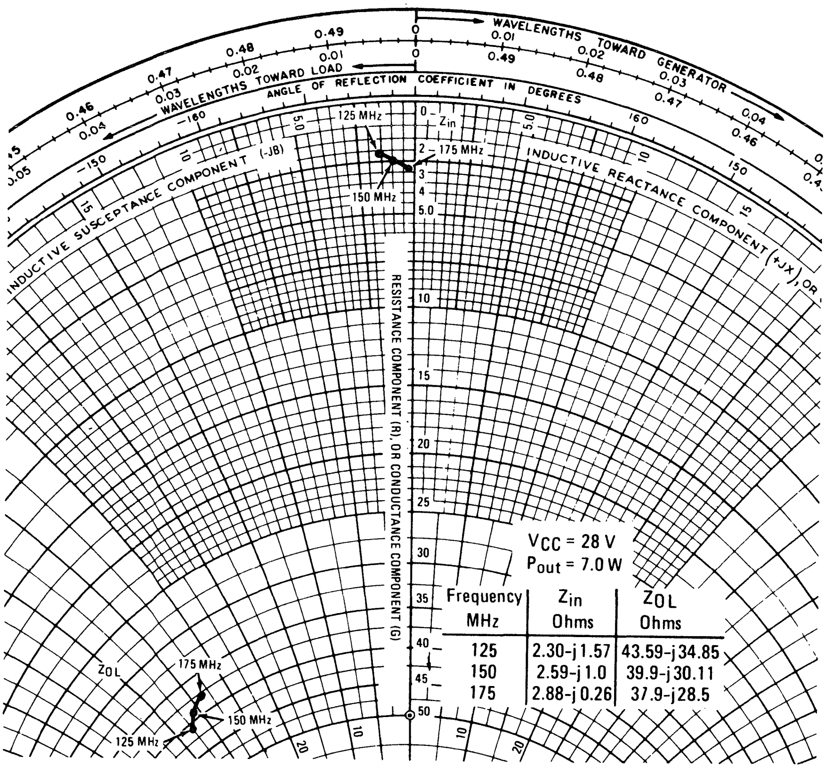



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 125 | 2.30-j1.57 | 43.59-j34.85 |
| 150 | 2.59-j1.0 | 39.9-j30.11 |
| 175 | 2.88-j0.26 | 37.9-j28.5 |

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# 2N5642

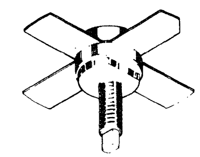
## The RF Line

### NPN SILICON RF POWER TRANSISTOR

20 W – 175 MHz

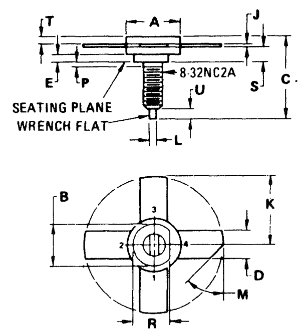
RF POWER
TRANSISTOR

NPN SILICON



. . . designed primarily for wideband large-signal amplifier stages in the 125-175 MHz frequency range.

- Specified 28 Volt, 175 MHz Characteristics –
  Output Power = 20 Watts
  Minimum Gain = 8.2 dB
  Efficiency = 60%
- Characterized from 125 to 175 MHz
- Includes Series Equivalent Impedances




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | $45^o$ NOM | | $45^o$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 3.0 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 30<br>171 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.

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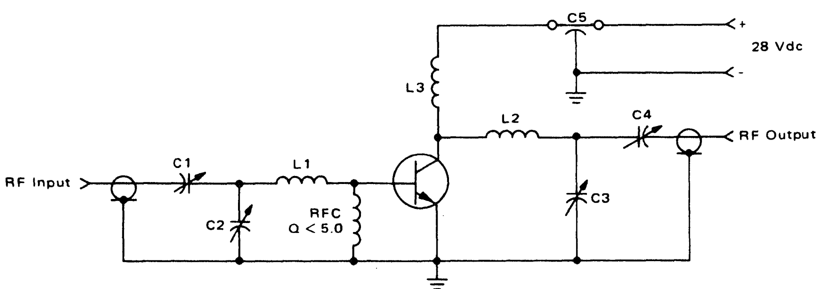
***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 200 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 22 | 35 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 20 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $G_{PE}$ | 8.2 | 10.2 | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 20 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |

Note 1: Pulsed through 25 mH inductor.
*Indicates JEDEC Registered Data.

**FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC**




| | |
|---|---|
| C1 | 3.0-30 pF |
| C2, C3, C4 | 9.0-180 pF |
| C5 | 0.1 $\mu$F |
| L1 | 1" Straight #14 AWG |
| L2 | 1 Turn #16 AWG, 1/4" I.D. |
| L3 | 0.22 $\mu$H |

FIGURE 2 – OUTPUT POWER versus FREQUENCY

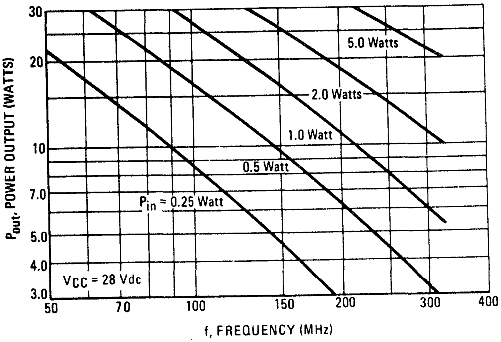



FIGURE 3 – OUTPUT POWER versus FREQUENCY

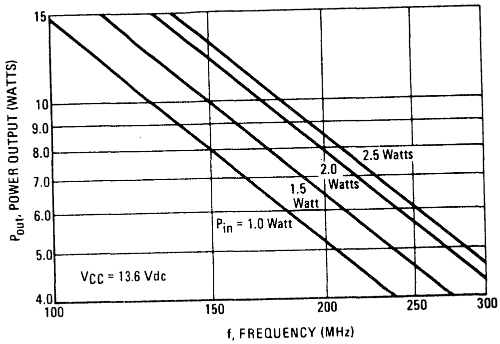
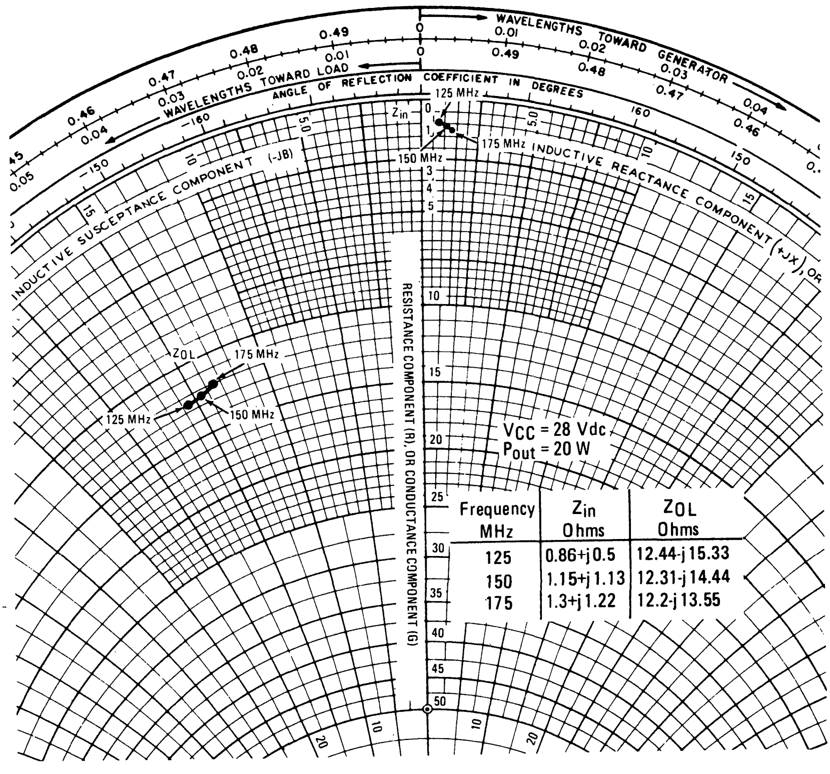



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 125 | 0.86+j0.5 | 12.44-j15.33 |
| 150 | 1.15+j1.13 | 12.31-j14.44 |
| 175 | 1.3+j1.22 | 12.2-j13.55 |

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**Semiconductors**
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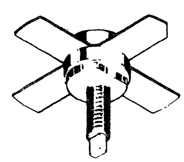
# 2N5643

## The RF Line

40 W – 175 MHz

RF POWER
TRANSISTOR

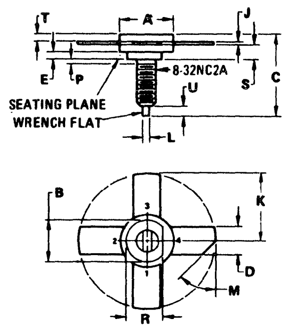
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal amplifier stages in the 125-175 MHz frequency range.

- Specified 28 Volt, 175 MHz Characteristics –
  - Output Power = 40 Watts
  - Minimum Gain = 7.6 dB
  - Efficiency = 60%
- Characterized from 125 to 175 MHz
- Includes Series Equivalent Impedances




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 5.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 60<br>342 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

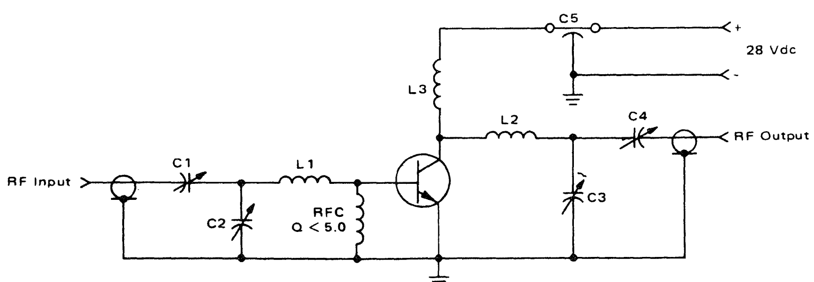
*Indicates JEDEC Registered Data.

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 45 | 65 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 40 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $G_{PE}$ | 7.6 | 8.1 | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 40 Watts, $V_{CE}$ = 28 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |

Note 1: Pulsed through 25 mH inductor.
*Indicates JEDEC Registered Data.

**FIGURE 1 — 175 MHz TEST CIRCUIT SCHEMATIC**




| | |
|---|---|
| C1, C2, C3, C4 | ARCO 464 25-280 pF |
| C5 | 0.1 µF |
| L1 | 1" Straight #14 AWG |
| L2 | 1 Turn #16 AWG, 1/4" I.D. |
| L3 | 0.22 µH |

FIGURE 2 – OUTPUT POWER versus FREQUENCY

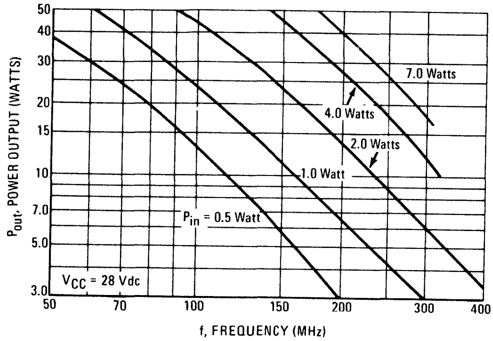



FIGURE 3 – OUTPUT POWER versus FREQUENCY

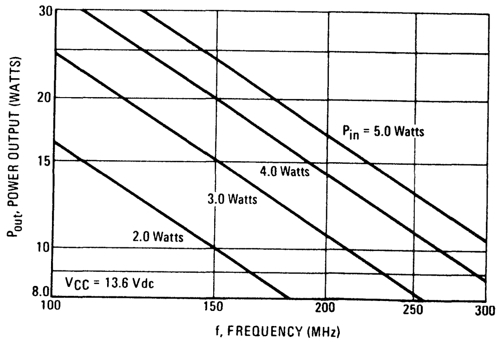
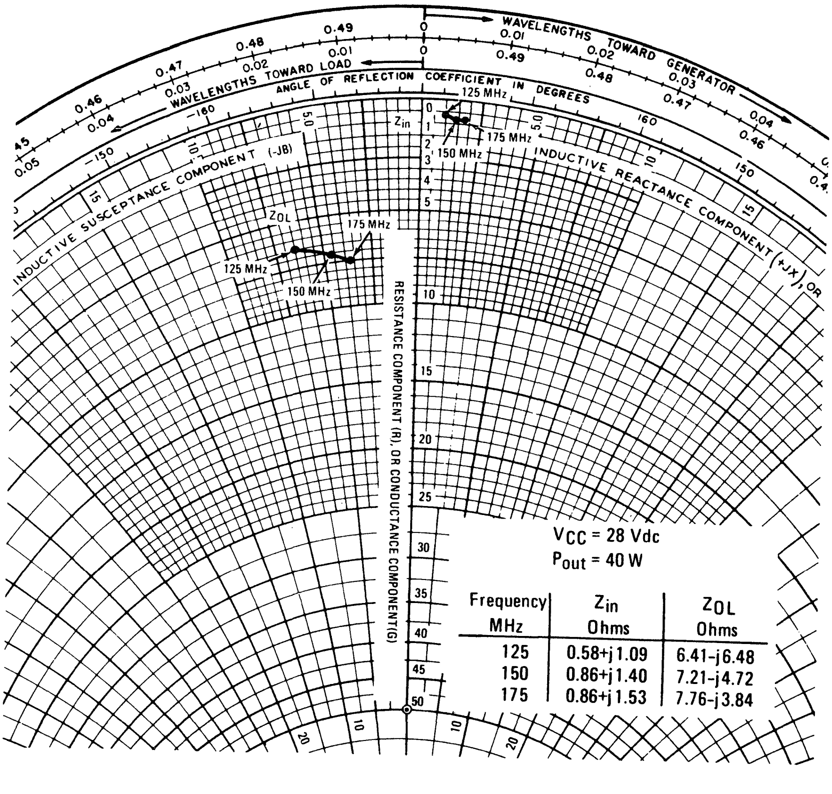



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 125 | 0.58+j1.09 | 6.41-j6.48 |
| 150 | 0.86+j1.40 | 7.21-j4.72 |
| 175 | 0.86+j1.53 | 7.76-j3.84 |

MOTOROLA
Semiconductors
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# MRF314
# MRF314A

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

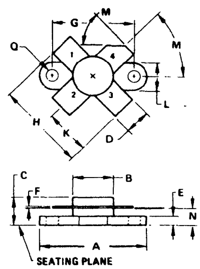
. . . designed primarily for wideband large-signal driver and output amplifier stages in the 30–200 MHz frequency range.

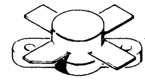
- Guaranteed Performance at 150 MHz, 28 Vdc
  Output Power = 30 Watts
  Minimum Gain = 10 dB
- 100% Tested for Load Mismatch at All Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability Applications

30 W–30-200 MHz

RF POWER
TRANSISTOR

NPN SILICON



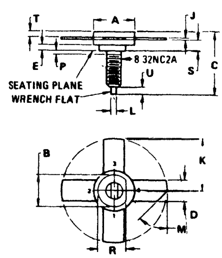


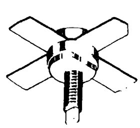
MRF314

STYLE 1
PIN 1 EMITTER
2 BASE
3 EMITTER
4 COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07





MRF314A

STYLE 1
PIN 1 EMITTER
2 BASE
3 EMITTER
4 COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

CASE 145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 3.4 | Adc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 82<br>0.47 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

### THERMAL CHARACTERISTICS

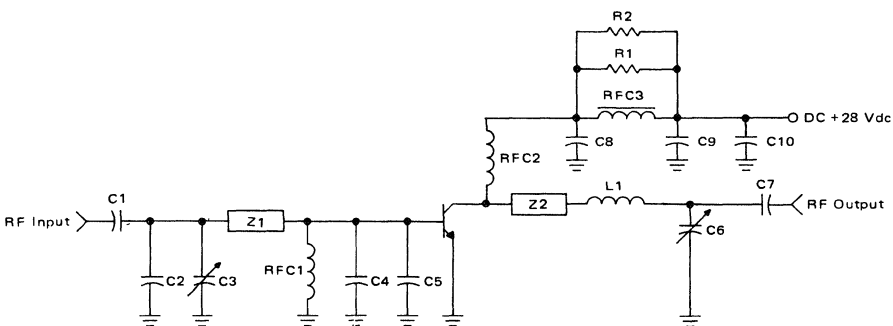
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.13 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 30 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 30 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 30 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 3.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 3.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 30 | 40 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 150 MHz) | $G_{PE}$ | 10 | 13.5 | – | db |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 150 MHz) | $\eta$ | 50 | – | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 150 MHz, VSWR = 30:1 all phase angles | – | No Degration in Power Output | | | |

**FIGURE 1 – 150 MHz TEST CIRCUIT**




C1, C7 – 18 pF, 100 mil ATC
C2 – 68 pF, 100 mil ATC
C3, C6 – Johanson #JMC 5501
C4 – 270 pF, 100 mil ATC
C5 – 240 pF, 100 mil ATC
C8, C9 – 100 pF Underwood
C10 – 1.0 μF Tantalum
L1 – 2 Turns, 2.5" #20 Wire, ID = 0.275"

R1, R2 – 10 Ω, 1.0 W
RFC1 – 15 μH Molded Coil
RFC2 – 2 Turns, 2.5" #20 Wire, ID = 0.2"
RFC3 – Ferroxcube VK200–19/4B
Z1 – Microstrip 0.168" W x 1.6" L
Z2 – Microstrip 0.168" W x 1.2" L
Board – Glass Teflon $\epsilon_R \approx 2.55$

## TYPICAL PERFORMANCE CURVES

FIGURE 2 – OUTPUT POWER versus INPUT POWER

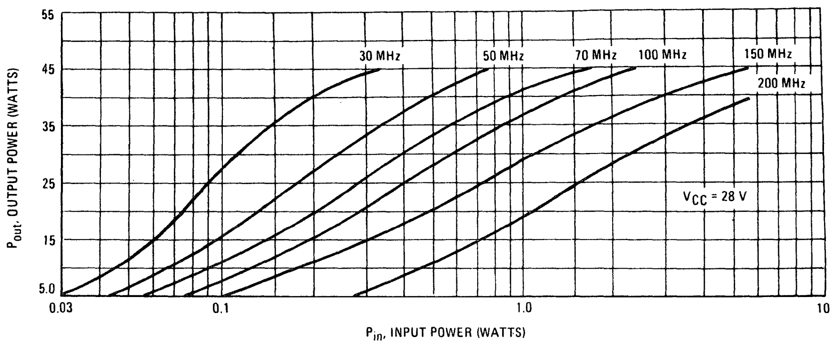



FIGURE 3 – OUTPUT POWER versus INPUT POWER

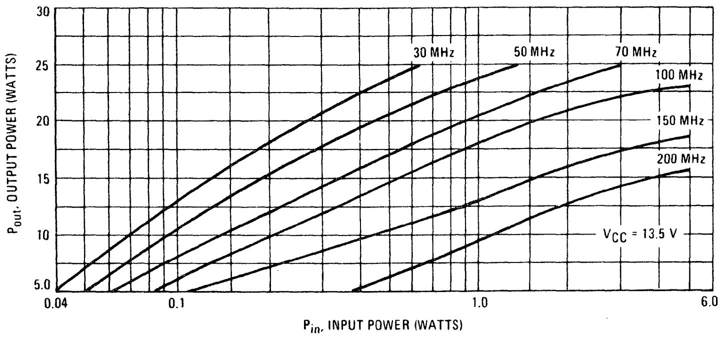



FIGURE 4 – POWER GAIN versus FREQUENCY

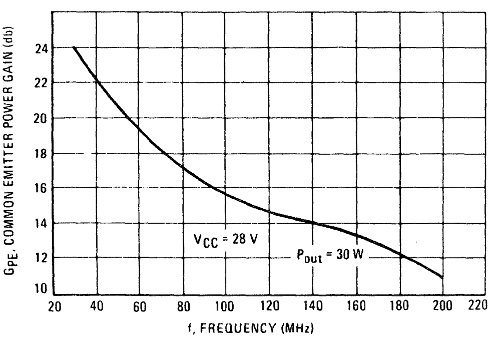



FIGURE 5 – EFFICIENCY (η%) versus FREQUENCY

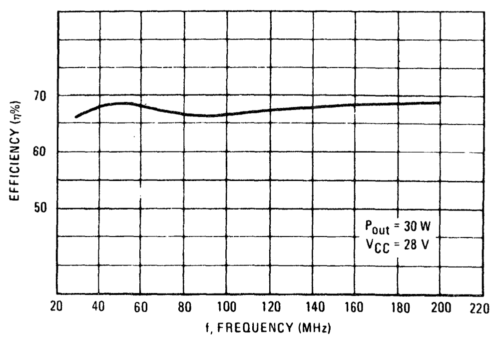
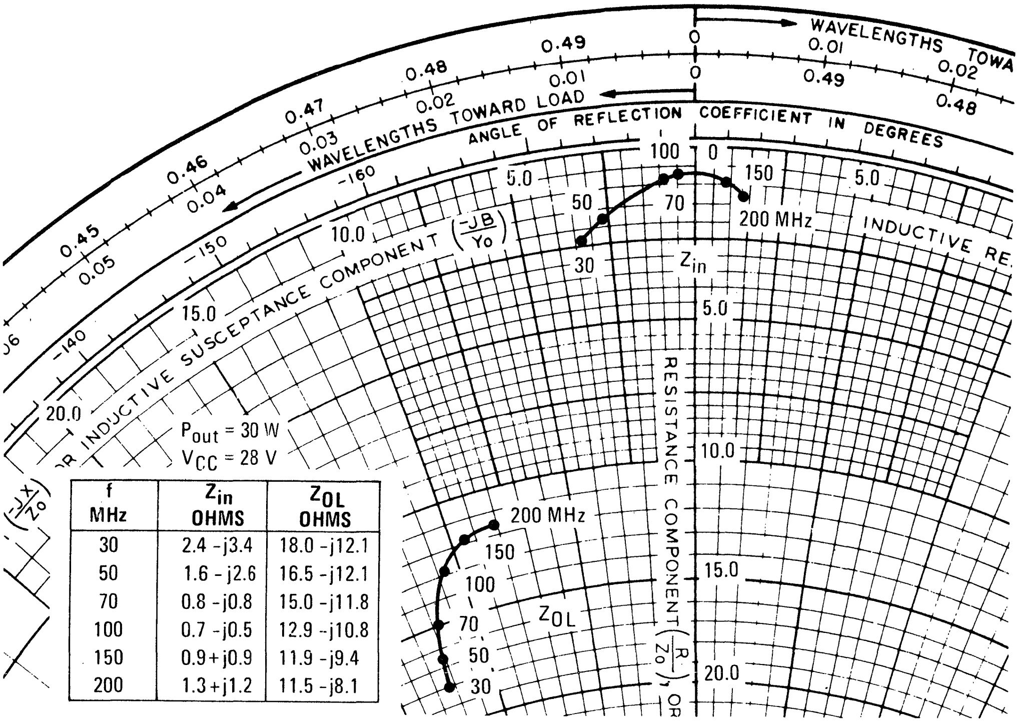
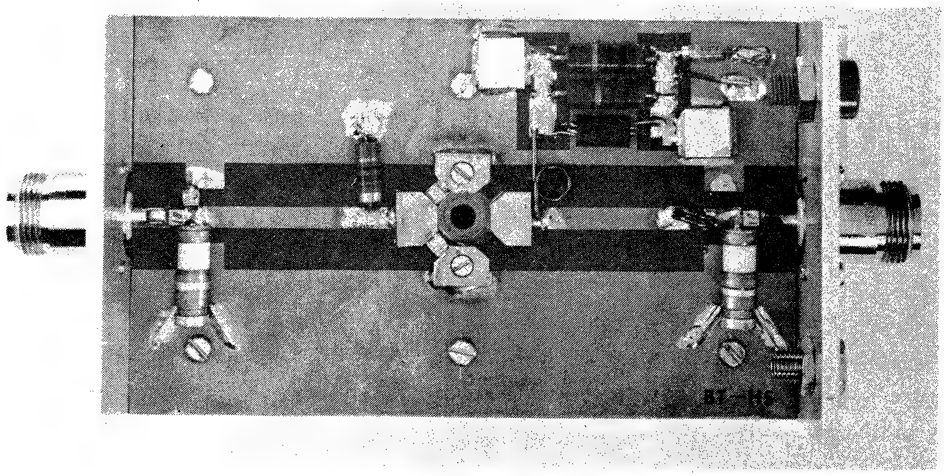


FIGURE 6 – SERIES EQUIVALENT INPUT/OUTPUT IMPEDANCE




| f MHz | $Z_{in}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 30 | 2.4 -j3.4 | 18.0 -j12.1 |
| 50 | 1.6 - j2.6 | 16.5 -j12.1 |
| 70 | 0.8 -j0.8 | 15.0 -j11.8 |
| 100 | 0.7 -j0.5 | 12.9 -j10.8 |
| 150 | 0.9+j0.9 | 11.9 -j9.4 |
| 200 | 1.3+j1.2 | 11.5 -j8.1 |

FIGURE 7 – TEST FIXTURE



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF315
# MRF315A

## The RF Line

45 W – 30-200 MHz

**RF POWER TRANSISTOR**

**NPN SILICON**

## NPN SILICON RF POWER TRANSISTOR

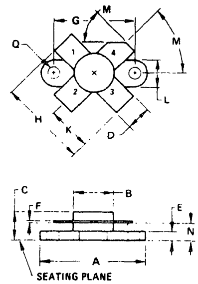
. . . designed primarily for wideband large-signal output amplifier stages in the 30–200 MHz frequency range.

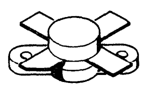
- Guaranteed Performance at 150 MHz, 28 Vdc

  Output Power = 45 Watts
  Minimum Gain = 9.0 dB

- 100% Tested for Load Mismatch at All Phase Angles with 30:1 VSWR

- Gold Metallization System for High Reliability Applications



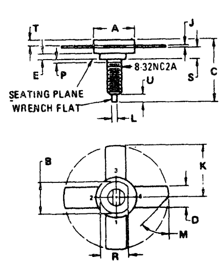



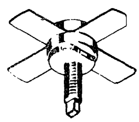
MRF315

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

CASE 211-07



MRF315A

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

CASE 145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 110<br>0.63 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

### THERMAL CHARACTERISTICS

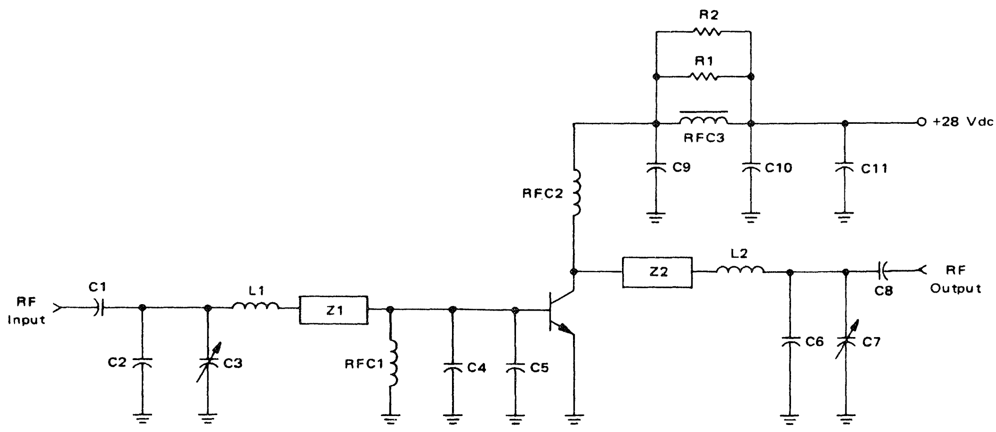
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.59 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 40 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 40 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 40 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 4.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$=0) | $I_{CBO}$ | – | – | 4.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 45 | 60 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 45 W, f = 150 MHz) | $G_{PE}$ | 9.0 | 11 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 45 W, f = 150 MHz) | $\eta$ | 50 | – | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 45 W, f = 150 MHz, VSWR = 30:1 all phase angles) | No Degradation in Power Output | | | | |

**FIGURE 1 — 150 MHz TEST CIRCUIT**




C1 — 30 pF, 100 mil ATC
C2 — 47 pF, 100 mil ATC
C3, C7 — Johanson #JMC 5501
C4, C5 — 200 pF, 100 mil ATC
C6 — 24 pF, 100 mil ATC
C8 — 27 pF, 100 mil ATC
C9, C10 — 100 pF Underwood
C11 — 1.0 μF Tantalum

L1 — 0.5" #18 Wire
L2 — 2 Turns, 1.5" #20 Wire, ID = 0.15"
Z1, Z2 — Microstrip 0.168" W x 1.25" L
RFC1 — 15 μH Molded Coil
RFC2 — 2 Turns, 2.5" #18 Wire, ID = 0.2"
RFC3 — Ferroxcube VK200—19/4B
R1, R2 — 10 Ω, 1.0 W
Board — Glass Teflon $\epsilon_R \approx 2.55$

## TYPICAL PERFORMANCE CURVES

FIGURE 2 – OUTPUT POWER versus INPUT POWER

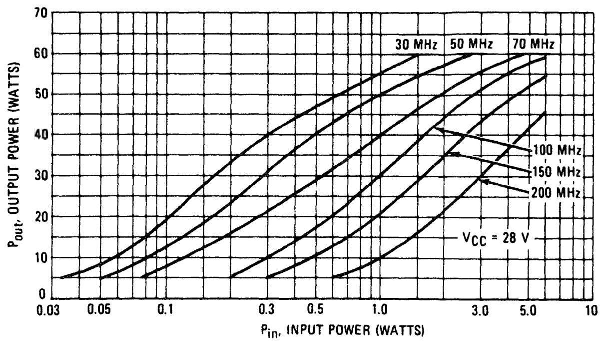



FIGURE 3 – OUTPUT POWER versus INPUT POWER

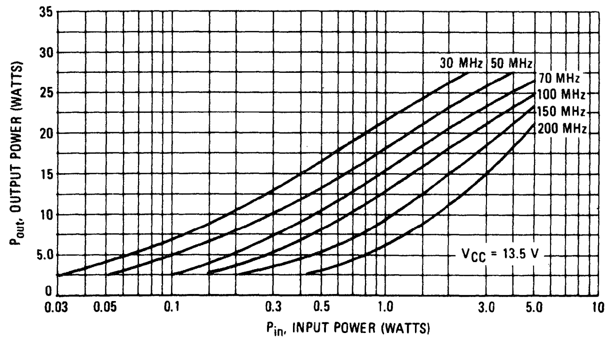



FIGURE 4 – POWER GAIN versus FREQUENCY

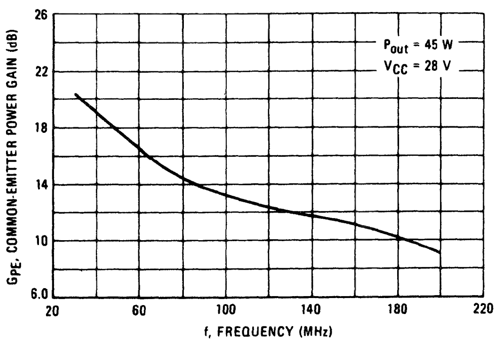



FIGURE 5 – EFFICIENCY versus FREQUENCY

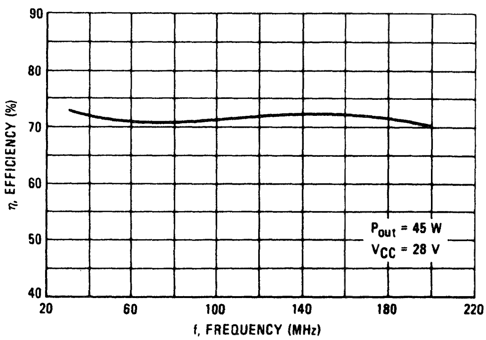
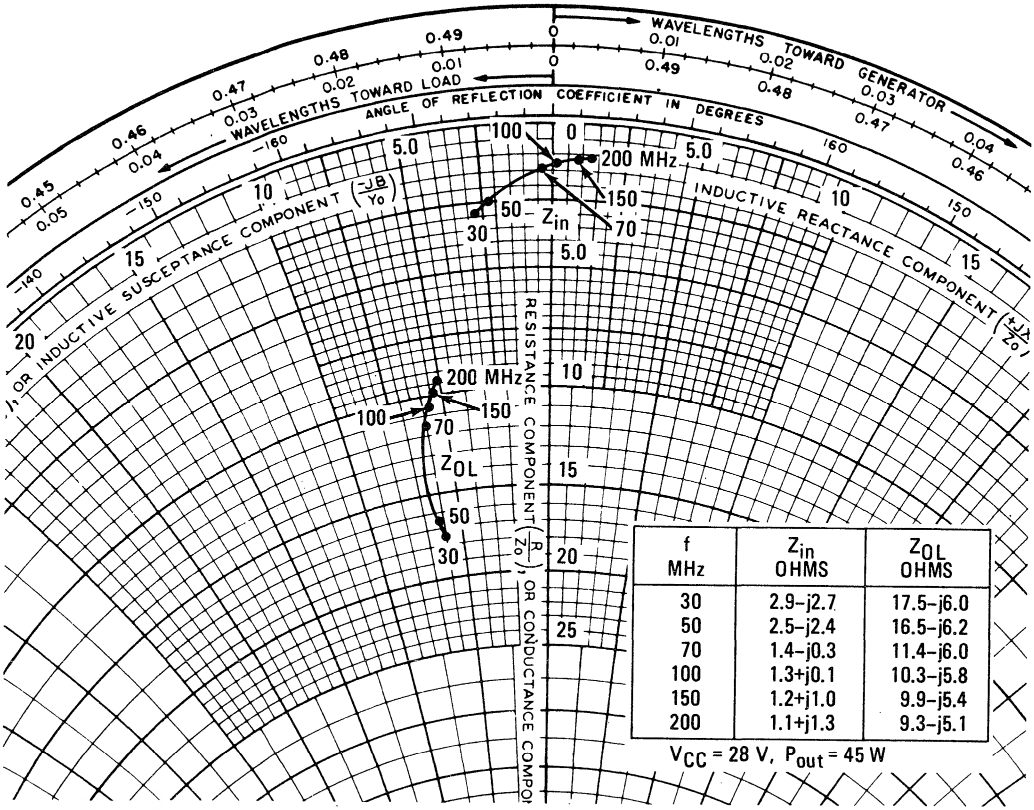


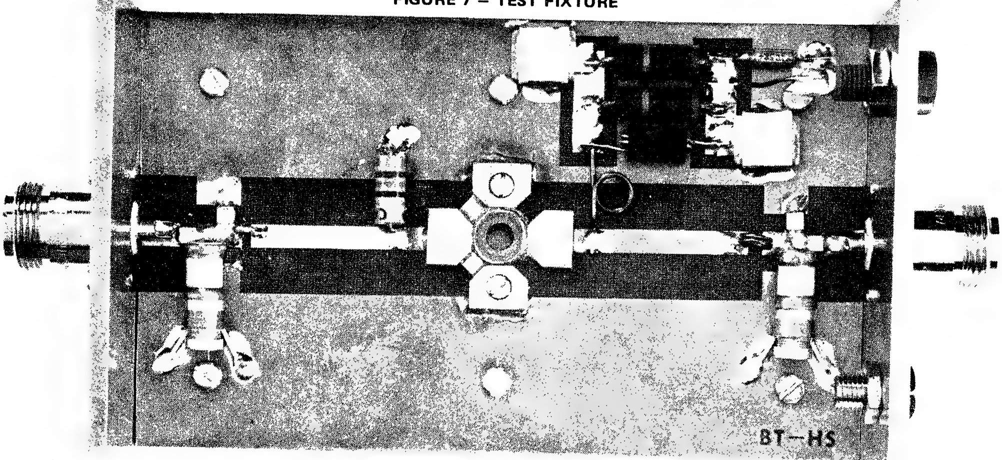
FIGURE 6 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| f MHz | $Z_{in}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 30 | 2.9–j2.7 | 17.5–j6.0 |
| 50 | 2.5–j2.4 | 16.5–j6.2 |
| 70 | 1.4–j0.3 | 11.4–j6.0 |
| 100 | 1.3+j0.1 | 10.3–j5.8 |
| 150 | 1.2+j1.0 | 9.9–j5.4 |
| 200 | 1.1+j1.3 | 9.3–j5.1 |

$V_{CC}$ = 28 V, $P_{out}$ = 45 W

FIGURE 7 – TEST FIXTURE



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

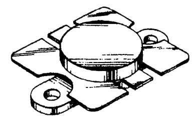
# MRF316

## The RF Line

**80 W – 30-200 MHz**

**CONTROLLED "Q"
BROADBAND RF POWER
TRANSISTOR**

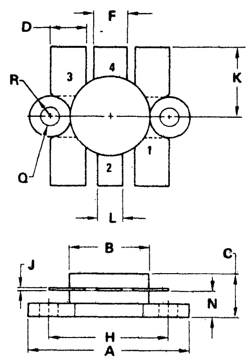
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal output amplifier stages in the 30–200 MHz frequency range.

- Guaranteed Performance at 150 MHz, 28 Vdc
  Output Power = 80 Watts
  Minimum Gain = 10 dB
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability Applications




STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

**CASE 316-01**

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>Peak | $I_C$ | 9.0<br>13.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 220<br>1.26 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | $^oC$ |

### THERMAL CHARACTERISTICS

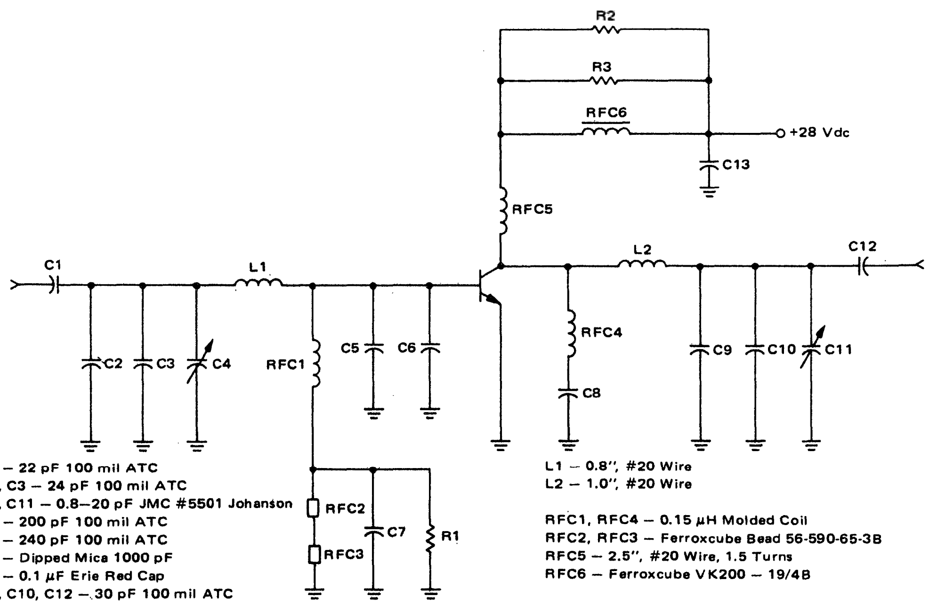
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.8 | $^oC/W$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 50 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 4.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 130 | 200 | pF |
| **NARROW BAND FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 80 W, f = 150 MHz) | $G_{PE}$ | 10 | 13 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 80 W, f = 150 MHz) | $\eta$ | 55 | – | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 80 W CW, f = 150 MHz, VSWR 30:1 all phase angles) | $\psi$ | No Degradation in Power Output | | | |

**FIGURE 1 — 150 MHz TEST AMPLIFIER**




C1 – 22 pF 100 mil ATC
C2, C3 – 24 pF 100 mil ATC
C4, C11 – 0.8–20 pF JMC #5501 Johanson
C5 – 200 pF 100 mil ATC
C6 – 240 pF 100 mil ATC
C7 – Dipped Mica 1000 pF
C8 – 0.1 µF Erie Red Cap
C9, C10, C12 – 30 pF 100 mil ATC
C13 – 1.0 µF Tantalum

L1 – 0.8", #20 Wire
L2 – 1.0", #20 Wire

RFC1, RFC4 – 0.15 µH Molded Coil
RFC2, RFC3 – Ferroxcube Bead 56-590-65-3B
RFC5 – 2.5", #20 Wire, 1.5 Turns
RFC6 – Ferroxcube VK200 – 19/4B

R1 – 10 Ω, 1/2 W
R2, R3 – 10 Ω, 1 W

## TYPICAL PERFORMANCE CURVES

FIGURE 2 – OUTPUT POWER versus INPUT POWER

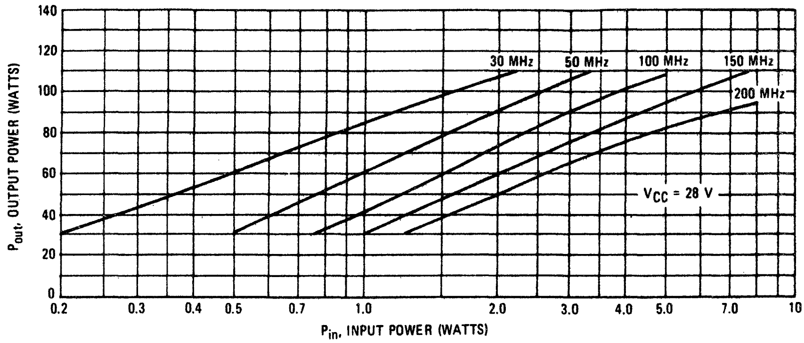



FIGURE 3 – POWER GAIN versus FREQUENCY

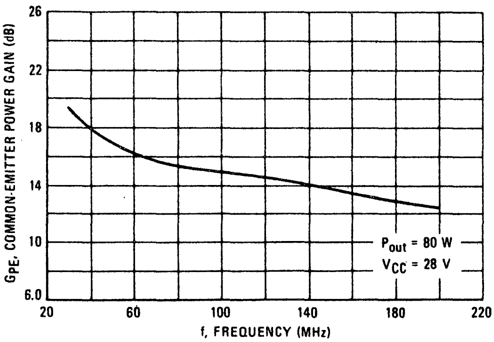



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE
f = 100 MHz

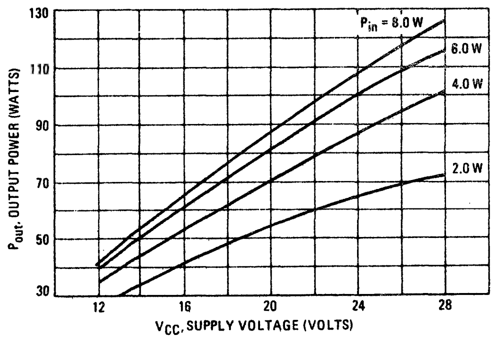



FIGURE 5 – OUTPUT POWER versus SUPPLY VOLTAGE
f = 150 MHz

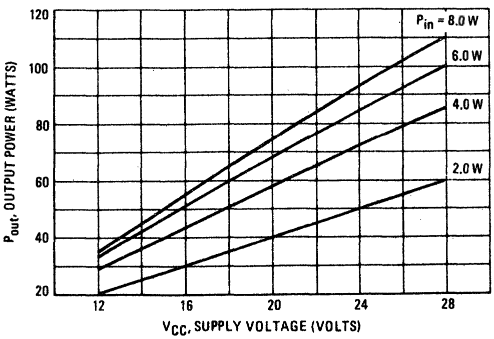



FIGURE 6 – OUTPUT POWER versus SUPPLY VOLTAGE
f = 200 MHz

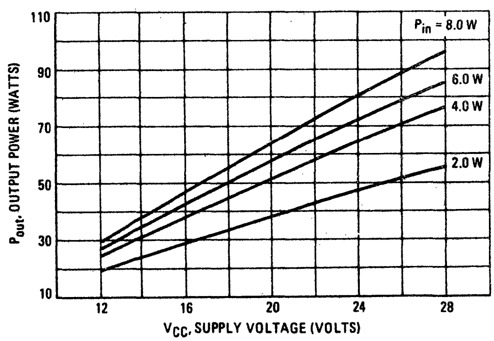
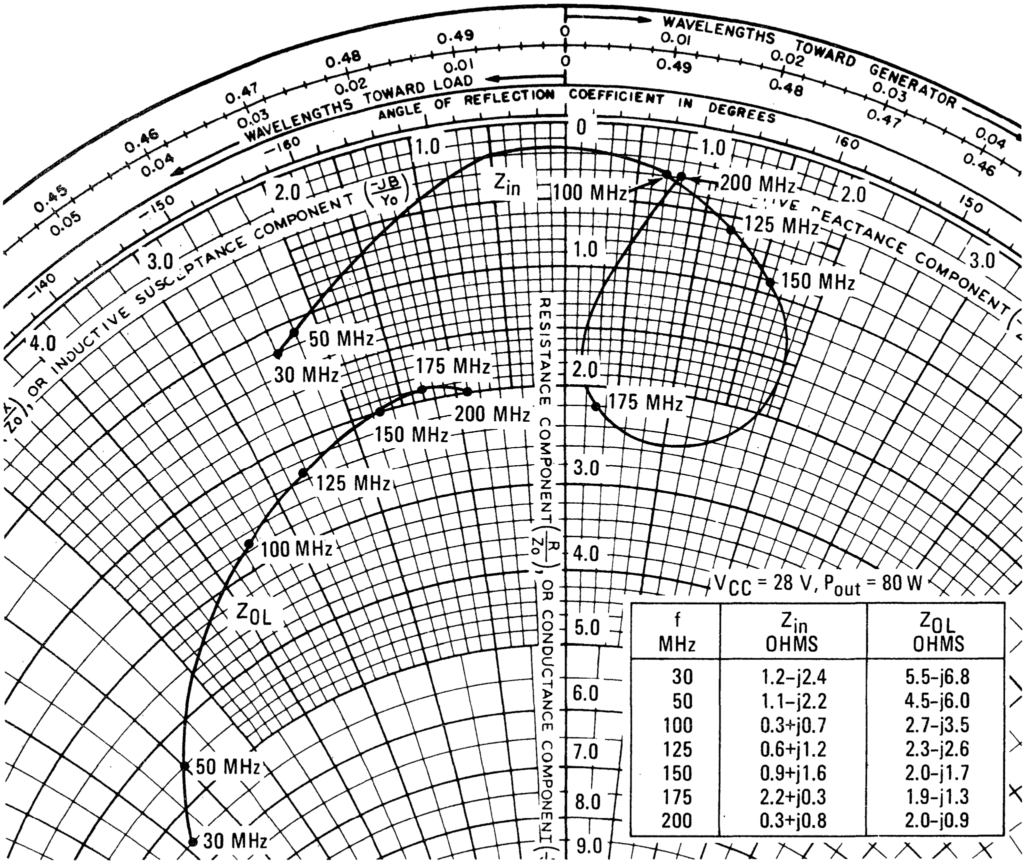
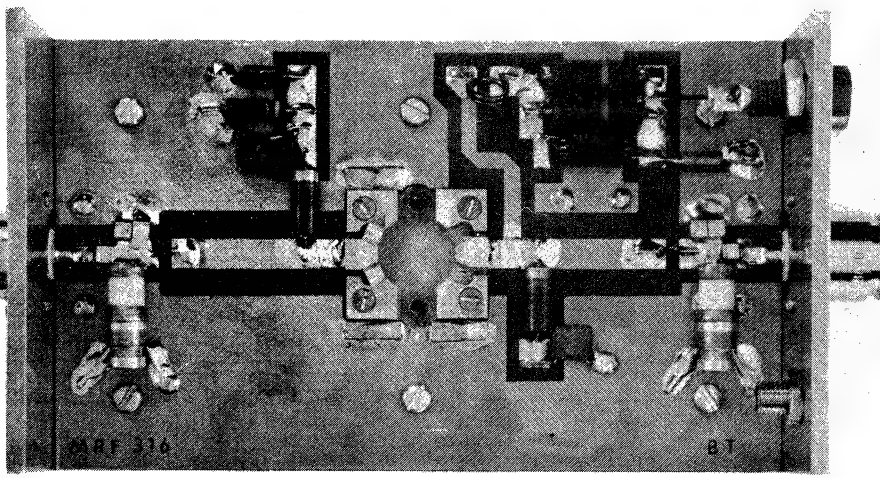


FIGURE 7 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| f MHz | Zin OHMS | ZOL OHMS |
|---|---|---|
| 30 | 1.2–j2.4 | 5.5–j6.8 |
| 50 | 1.1–j2.2 | 4.5–j6.0 |
| 100 | 0.3+j0.7 | 2.7–j3.5 |
| 125 | 0.6+j1.2 | 2.3–j2.6 |
| 150 | 0.9+j1.6 | 2.0–j1.7 |
| 175 | 2.2+j0.3 | 1.9–j1.3 |
| 200 | 0.3+j0.8 | 2.0–j0.9 |

FIGURE 8 – TEST FIXTURE



MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF317

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

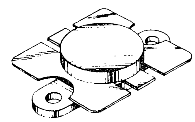
. . . designed primarily for wideband large signal output amplifier stages in 30 – 200 MHz frequency range.

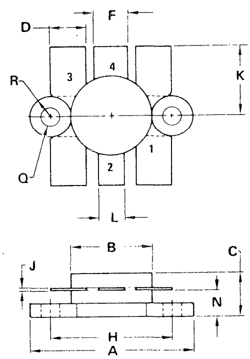
- Guaranteed Performance at 150 MHz and 28 Vdc
  Output Power = 100 W
  Minimum Gain = 9 dB
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch at All Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability
- High Output Saturation Power — Ideally Suited for 30 W Carrier/ 120 W Peak AM Amplifier Service
- Guaranteed Performance in Broadband Test Fixture

100 W – 30 - 200 MHz

CONTROLLED Q
BROADBAND RF POWER
TRANSISTOR

NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 65 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak (10 seconds) | $I_C$ | 12<br>18 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate Above $25^oC$ | $P_D$ | 270<br>1.54 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | $^oC$ |

### THERMAL CHARACTERISTICS

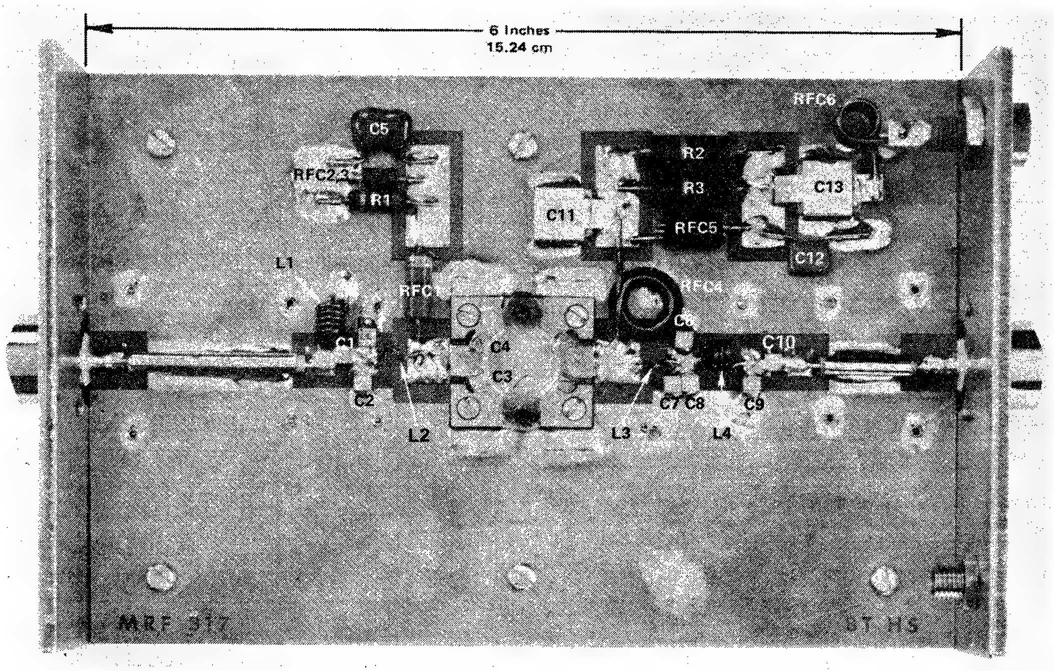
| | | | |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.65 | $^oC/W$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF Amplifiers.

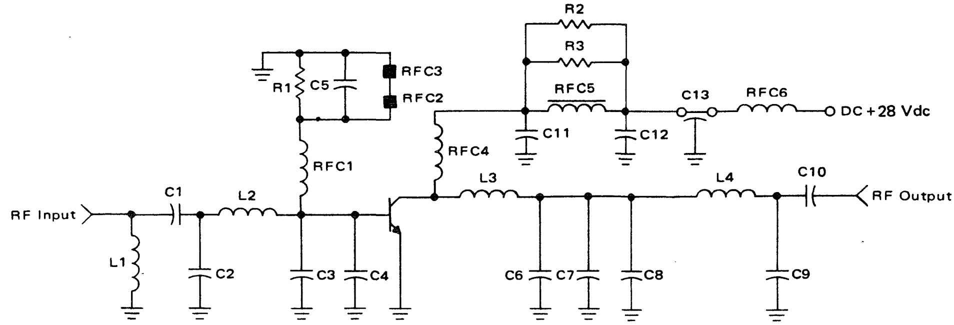
**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 35 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 65 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 65 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 25 | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 200 | 250 | pF |
| **FUNCTIONAL TESTS (FIGURE 2)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 100 W, f = 150 MHz, $I_C$(Max) = 6.5 Adc) | $G_{PE}$ | 9.0 | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 100 W, f = 150 MHz, $I_C$(Max) = 6.5 Adc) | $\eta$ | 55 | 60 | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 100 W CW, f = 150 MHz, VSWR = 30:1 all phase angles) | $\Psi$ | No Degradation in Output Power | | | |

FIGURE 1 – BROADBAND (110-160 MHz) TEST FIXTURE



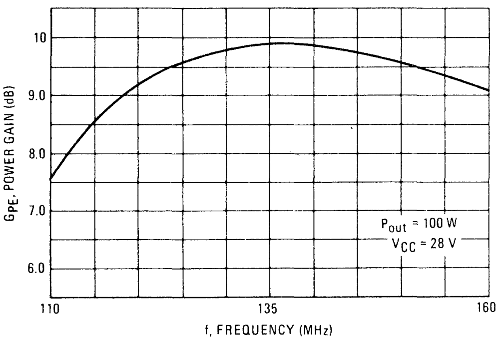
## FIGURE 2 — 110-160 MHz BROADBAND AMPLIFIER — TEST FIXTURE



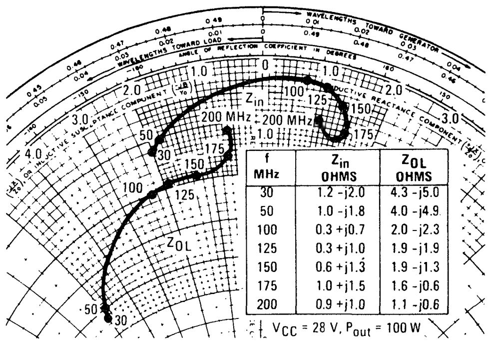

C1, C9 — 39 pF, 100 mil ATC
C2 — 120 pF, 100 mil ATC
C3, C4 — 360 pF, 100 mil ATC
C5 — 1000 pF Dipped Mica
C6, C7 — 100 pF, 100 mil ATC*
C8 — 18 pF, 100 mil ATC*
C10 — 43 pF, 100 mil ATC
C11 — 60 pF, Underwood
C12 — 0.1 μF Erie Redcap
C13 — 1000 pF, Underwood J102

L1 — 50 nH
L2 — 6.0 nH
L3 — 8.0 nH
L4 — 32 nH
RFC1 — 0.15 μH Molded Coil
RFC2, RFC3 — Ferroxcube Bead 56-590-65/3B
RFC4 — 1 Turn, #18 Wire, 2.0" L
RFC5 — Ferroxcube VK200 19/4B
RFC6 — 7 Turns, #18 Wire, 0.3" ID
R1 — 10 Ω 1/2 W
R2, R3 — 10 Ω 1 W
*Combination of C6, C7, C8 equals 220 pF

## FIGURE 3 — POWER GAIN versus FREQUENCY BROADBAND TEST FIXTURE

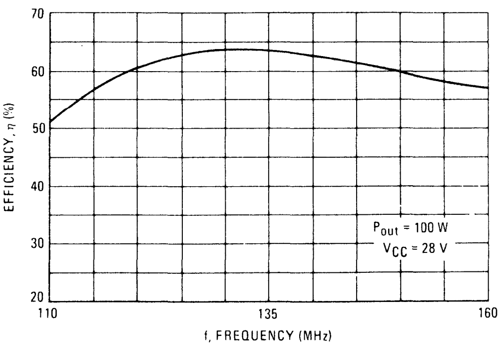



## FIGURE 4 — SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE

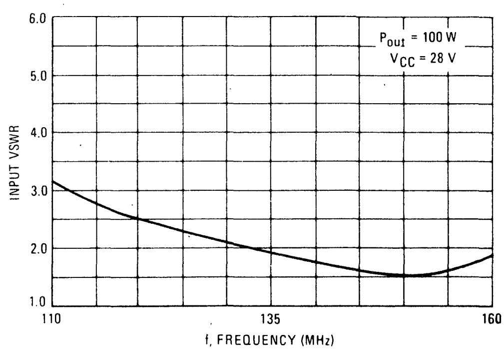



| f MHz | $Z_{in}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 30 | 1.2 -j2.0 | 4.3 -j5.0 |
| 50 | 1.0 -j1.8 | 4.0 -j4.9 |
| 100 | 0.3 +j0.7 | 2.0 -j2.3 |
| 125 | 0.3 +j1.0 | 1.9 -j1.9 |
| 150 | 0.6 +j1.3 | 1.9 -j1.3 |
| 175 | 1.0 +j1.5 | 1.6 -j0.6 |
| 200 | 0.9 +j1.0 | 1.1 -j0.6 |

## FIGURE 5 — EFFICIENCY versus FREQUENCY BROADBAND TEST FIXTURE




## FIGURE 6 — INPUT VSWR versus FREQUENCY BROADBAND TEST FIXTURE



## TYPICAL PERFORMANCE CURVES

FIGURE 7 — OUTPUT POWER versus INPUT POWER

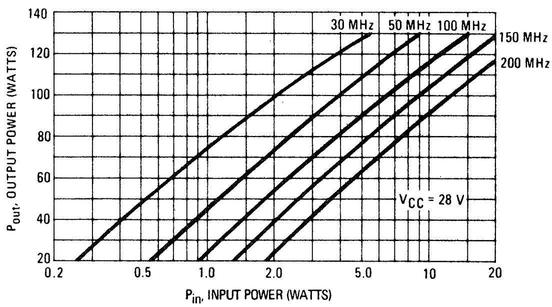



FIGURE 8 — POWER GAIN versus FREQUENCY

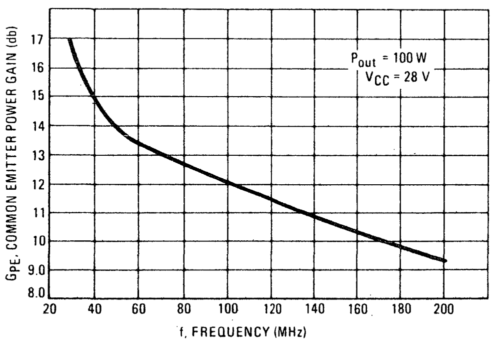



FIGURE 9 — POWER OUTPUT versus SUPPLY VOLTAGE
f = 100 MHz

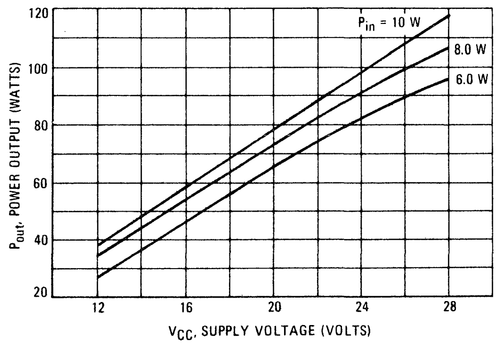



FIGURE 10 — POWER OUTPUT versus SUPPLY VOLTAGE
f = 150 MHz

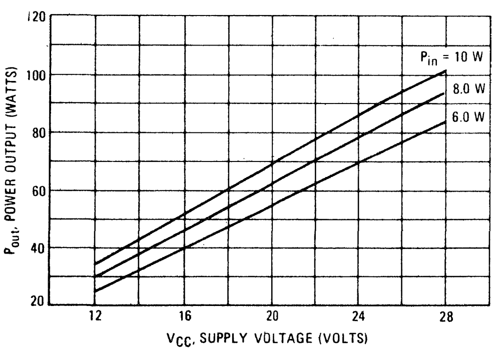
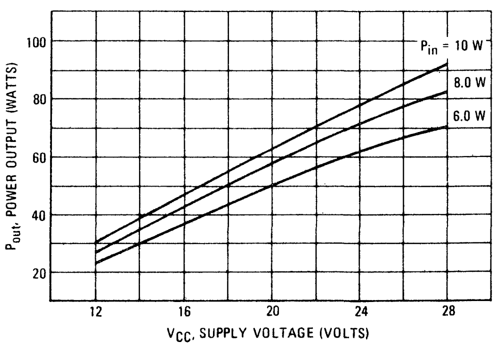
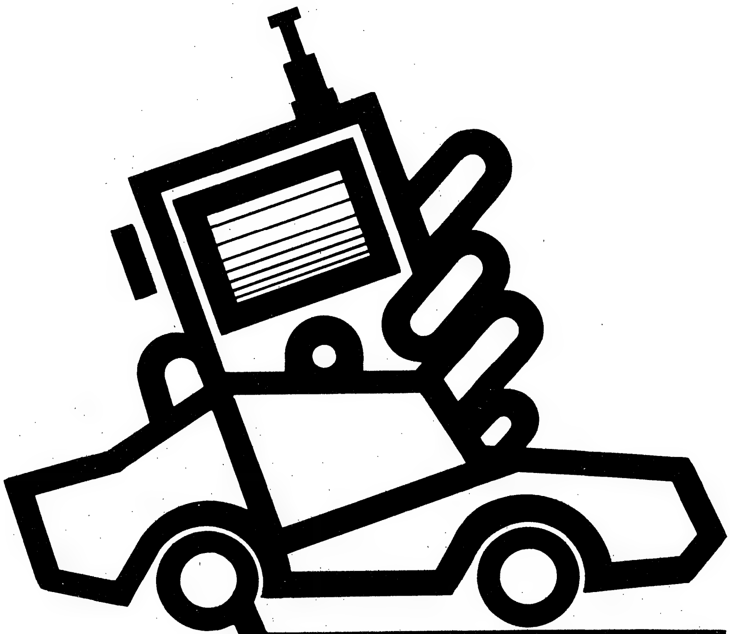



FIGURE 11 — POWER OUTPUT versus SUPPLY VOLTAGE
f = 200 MHz



# CHAPTER 8



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF229
# MRF230

## The RF Line

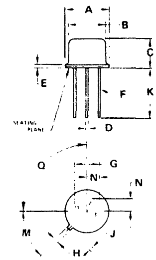
1.5 W – 90 MHz
RF POWER
TRANSISTOR
NPN SILICON

### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt, mid-band large-signal amplifier applications in industrial and commercial FM equipment operating in the 40 to 100 MHz range.

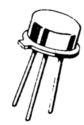
- Specified 12.5 Volt, 90 MHz Characteristics –
  Output Power = 1.5 Watts
  Minimum Gain = 10 dB
  Efficiency = 55%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Characterized with Parallel Equivalent Large-Signal Impedance Parameters
- MRF229 – Emitter Connected to Case
- MRF230 – Collector Connected to Case

MRF229
CASE 79-03

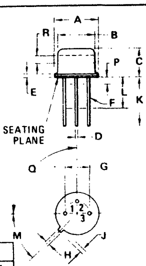



STYLE 5:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |



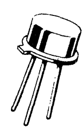
MRF230
CASE 79-02
TO-39




STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

All JEDEC dimensions and notes apply

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.5 | Adc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 35 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.

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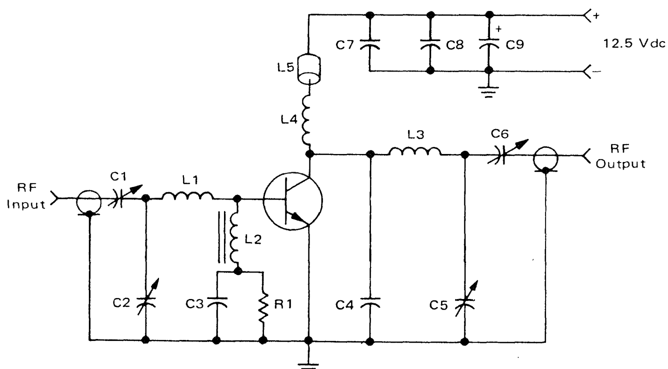
**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.25 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 25 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.5 W, f = 90 MHz) | $G_{PE}$ | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.5 W, f = 90 MHz) | $\eta$ | 55 | – | % |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.5 W, f = 90 MHz, $T_C \leqslant 25°C$) | – | VSWR > 30:1 Through All Phase Angles in 3 Second Interval After Which Devices Will Meet $G_{PE}$ Test Limits | | |

FIGURE 1 — 90 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1 | 5.0-80 pF, ARCO 462 | C9 | 20 μF, 15 Vdc TANTALUM |
| C2,C6 | 25-280 pF, ARCO 464 | L1 | 2 Turns, #18 AWG, 3/8" I.D. 3/8" Long |
| C3 | 250 pF UNELCO | L2 | 2.5 Turns, #20 AWG, on Ferrite Bead. FERROXCUBE 56-590-65-3B |
| C4 | 10 pF UNELCO | L3 | 3 Turns, #18 AWG, 3/8" I.D., 1/2" Long |
| C5 | 9.0-180 pF, ARCO 463 | L4 | 0.68 μH, 9230-16 MILLER Molded Choke |
| C7 | 1000 pF UNELCO | L5 | Ferrite Bead, FERROXCUBE 56-590-65-3B |
| C8 | 0.47 μF ERIE Disc Ceramic | R1 | 4.7 OHM, 1/2 W, 10% Carbon |

Input/Output Connectors — Type BNC

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FIGURE 2 – OUTPUT POWER versus INPUT POWER

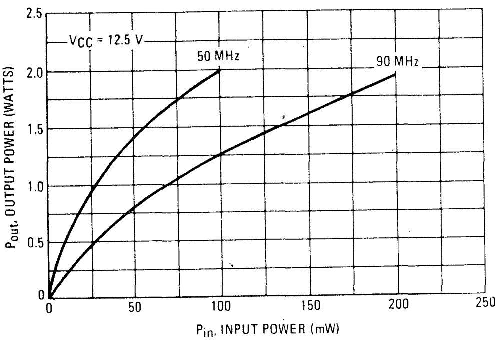



FIGURE 3 – OUTPUT POWER versus FREQUENCY

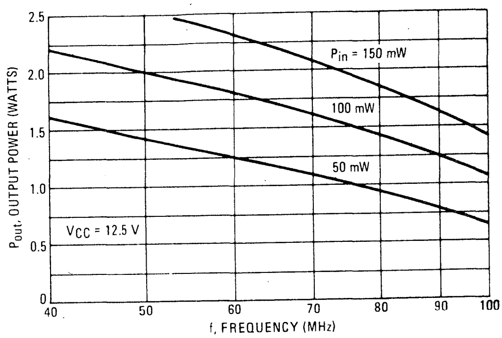



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

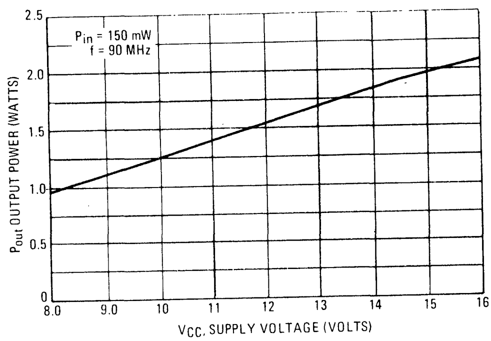
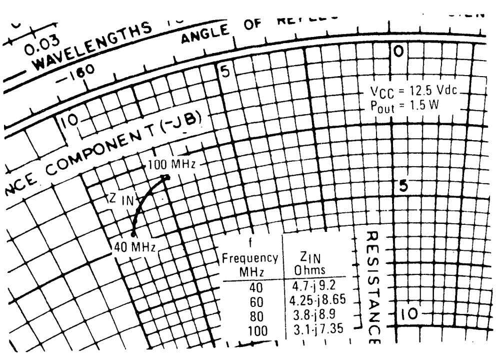


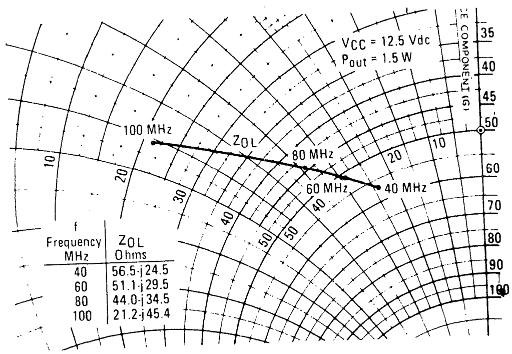

FIGURE 5

SERIES EQUIVALENT INPUT IMPEDANCE




| f Frequency MHz | ZIN Ohms |
|---|---|
| 40 | 4.7-j 9.2 |
| 60 | 4.25-j8.65 |
| 80 | 3.8-j8.9 |
| 100 | 3.1-j7.35 |

SERIES EQUIVALENT OUTPUT IMPEDANCE




| f Frequency MHz | ZOL Ohms |
|---|---|
| 40 | 56.5-j24.5 |
| 60 | 51.1-j29.5 |
| 80 | 44.0-j34.5 |
| 100 | 21.2-j45.4 |

8

FIGURE 6 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

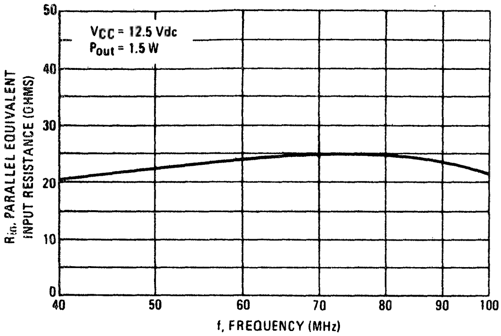



FIGURE 7 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

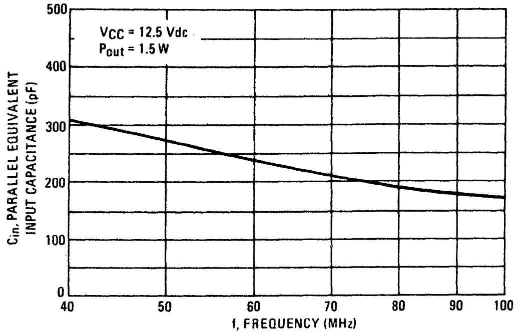



FIGURE 8 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY

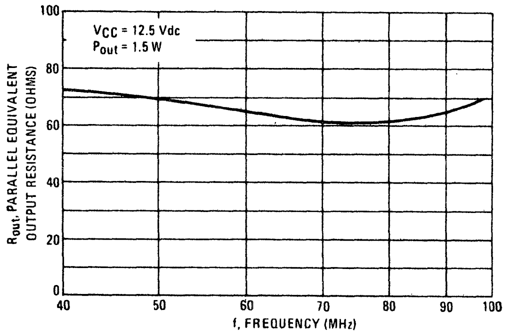
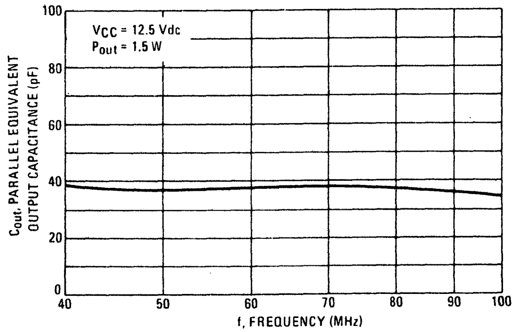



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY




8

MOTOROLA
Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF231

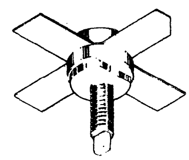
## The RF Line

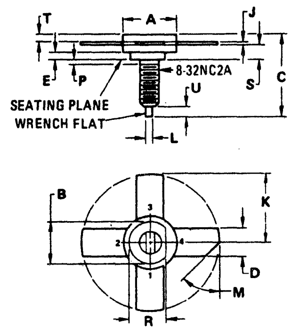
### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt, mid-band large-signal amplifier applications in industrial and commercial FM equipment operating in the 40 to 100 MHz range.

- Specified 12.5 Volt, 90 MHz Characteristics –
  Output Power = 3.5 Watts
  Minimum Gain = 10 dB
  Efficiency = 55%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Characterized with Parallel Equivalent Large-Signal Impedance Parameters

3.5 W – 90 MHz
RF POWER
TRANSISTOR
NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 10<br>57.1 | Watts<br>mW/$^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |
| Stud Torque (2) | – | 6.5 | In-Lb. |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 17.5 | $^oC/W$ |

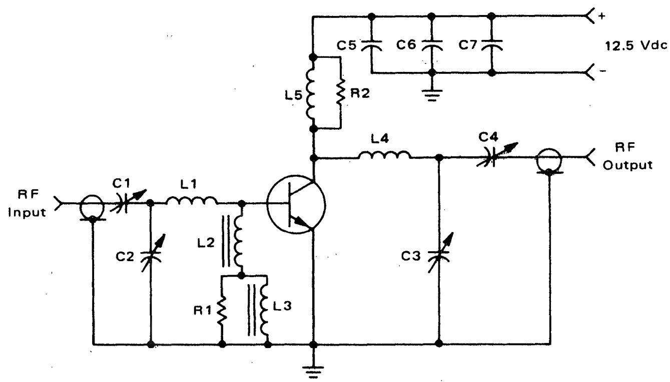
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.

(2) For repeated assembly use 5 In-Lb.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.25 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 25 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.5 W, f = 90 MHz) | $G_{PE}$ | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.5 W, f = 90 MHz) | $\eta$ | 55 | – | % |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 3.5 W, f = 90 MHz, $T_C \leqslant 25°C$) | – | VSWR > 30:1 Through All Phase Angles in 3 Second Interval After Which Devices Will Meet $G_{PE}$ Test Limits | | |

**FIGURE 1 – 90 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1,C3 | 9.0-180 pF, ARCO 463 | L3 | 1.5 µH, 9230-24 MILLER Molded Choke |
| C2,C4 | 25-280 pF, ARCO 464 | L4 | 3 Turns, #18 AWG, 3/8" I.D., 1/2" Long |
| C5 | 1000 pF, UNELCO | L5 | 10 Turns, Wound on R2 |
| C6 | 0.047 µF, ERIE Disc Ceramic | | |
| C7 | 10 µF, 15 Vdc TANTALUM | R1 | 15 Ohm, 1/2 W, 10% Carbon |
| L1 | 2 Turns, #18 AWG, 3/8" I.D., 1/2" Long | R2 | 220 Ohm, 1 W, Carbon |
| L2 | 22 µH, 9230-52 MILLER Molded Choke | Input/Output Connectors – Type BNC | |

8

FIGURE 2 – OUTPUT POWER versus INPUT POWER

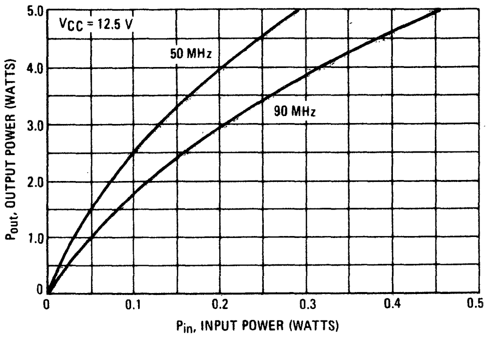



FIGURE 3 – OUTPUT POWER versus FREQUENCY

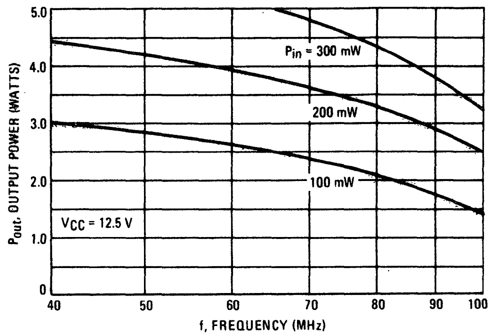



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

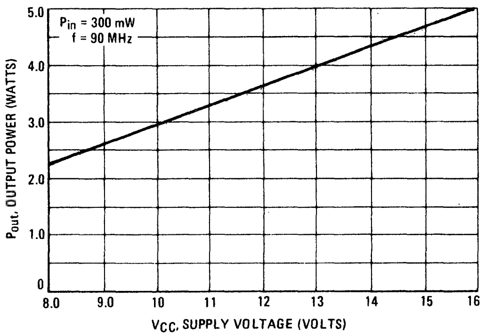
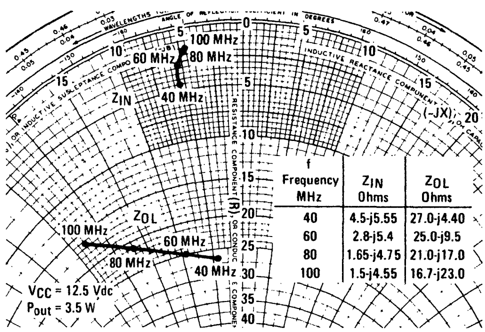



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| f Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 40 | 4.5-j5.55 | 27.0-j4.40 |
| 60 | 2.8-j5.4 | 25.0-j9.5 |
| 80 | 1.65-j4.75 | 21.0-j17.0 |
| 100 | 1.5-j4.55 | 16.7-j23.0 |

FIGURE 6 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

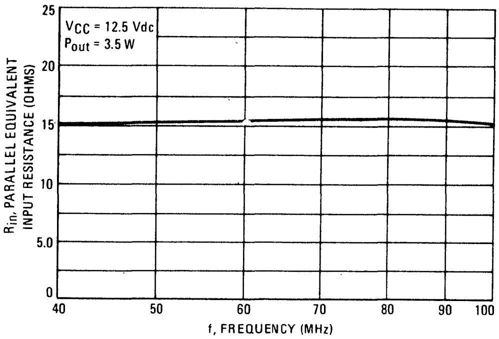



FIGURE 7 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

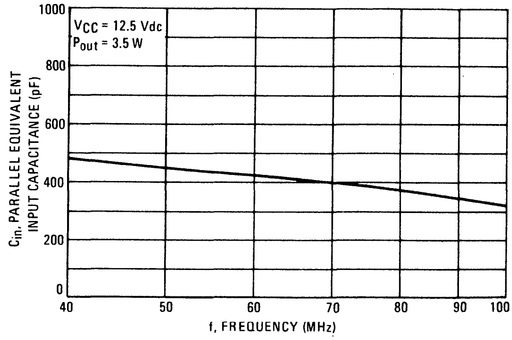



FIGURE 8 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY

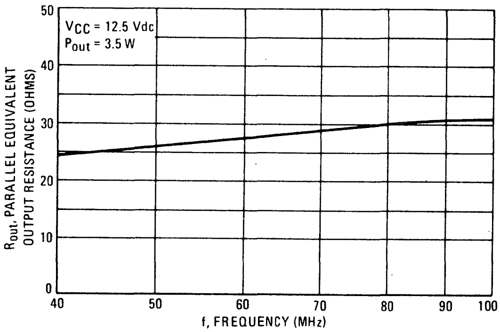
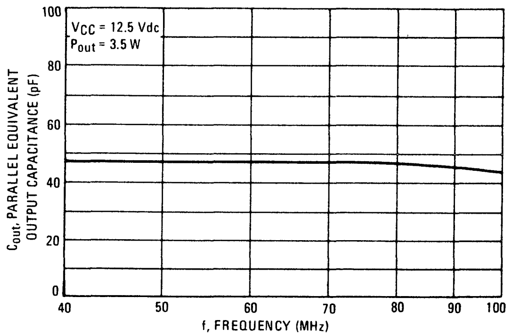



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF232

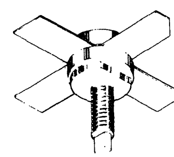
## The RF Line

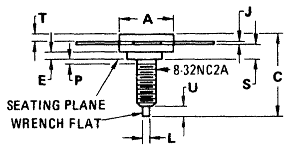
7.5 W – 90 MHz
RF POWER
TRANSISTOR
NPN SILICON

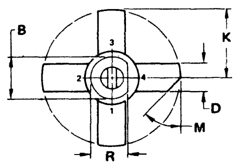
### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt, mid-band large-signal amplifier applications in industrial and commercial FM equipment operating in the 40 to 100 MHz range.

- Specified 12.5 Volt, 90 MHz Characteristics –
  Output Power = 7.5 Watts
  Minimum Gain = 9.0 dB
  Efficiency = 55%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Characterized with Parallel Equivalent Large-Signal Impedance Parameters






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.0 | Adc |
| Total Device Dissipation @ $T_C = 25^\circ C$ (1)<br>Derate above 25°C | $P_D$ | 20<br>114 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | In. Lb. |

### THERMAL CHARACTERISTICS

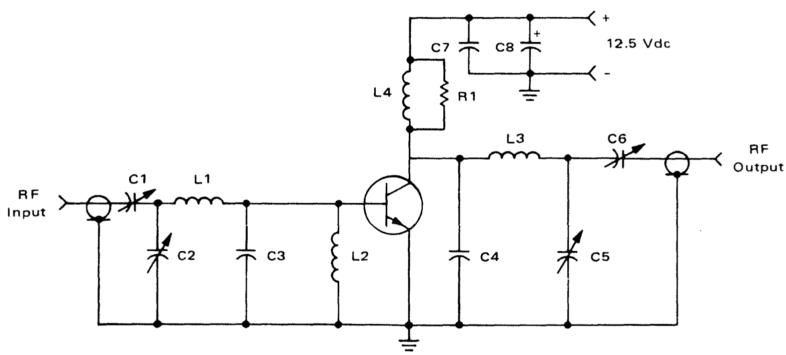
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 8.75 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.
(2) For repeated assembly use 5 In. Lb.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 55 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 7.5 W, f = 90 MHz) | $G_{PE}$ | 9.0 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 7.5 W, f = 90 MHz) | $\eta$ | 55 | – | % |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 7.5 W, f = 90 MHz, $T_C \leqslant 25°C$) | – | VSWR $>$30:1 Through All Phase Angle in a 3 Second Interval After Which Devices Will Meet $G_{PE}$ Test Limits. | | |

**FIGURE 1 – 90 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1,C6 | 5.0-80 pF, ARCO 462 | L1 | 3 Turns, #18 AWG, 3/8" I.D., 3/8" Long |
| C2,C5 | 9.0-180 pF, ARCO 463 | L2 | FERROXCUBE VK200-20-4B Ferrite Choke |
| C3,C4 | 100 pF UNELCO | L3 | 3 Turns, #18 AWG, 5/16" I.D., 3/8" Long |
| C7 | 1000 pF UNELCO | L4 | 10 Turns, #22 AWG, on R1 |
| C8 | 4.7 µF, 15 Vdc, TANTALUM | R1 | 340 Ohm, 1 W Carbon |

Input/Output Connectors – Type BNC

FIGURE 2 – OUTPUT POWER versus INPUT POWER

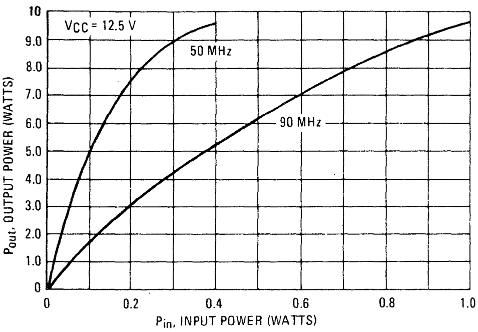



FIGURE 3 – OUTPUT POWER versus FREQUENCY

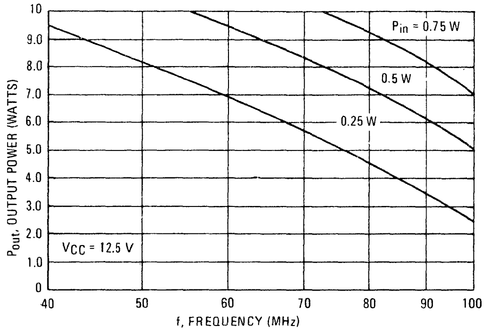



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

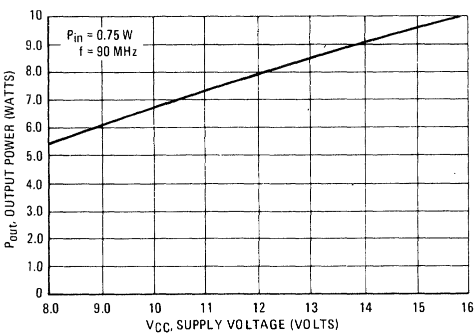
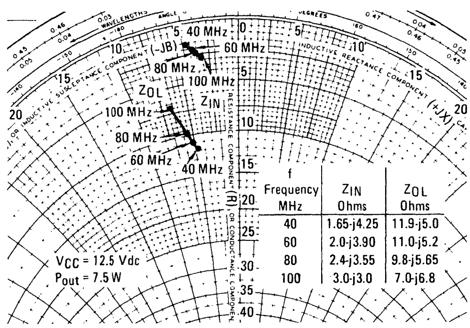



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| f Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 40 | 1.65-j4.25 | 11.9-j5.0 |
| 60 | 2.0-j3.90 | 11.0-j5.2 |
| 80 | 2.4-j3.55 | 9.8-j5.65 |
| 100 | 3.0-j3.0 | 7.0-j6.8 |

FIGURE 6 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

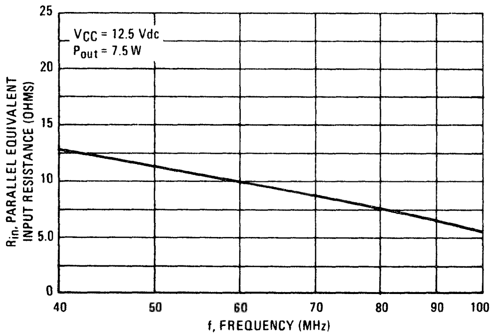



FIGURE 7 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

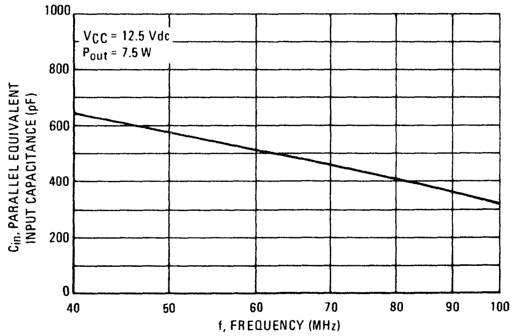



FIGURE 8 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY

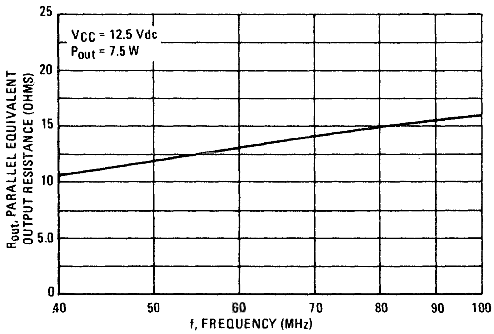
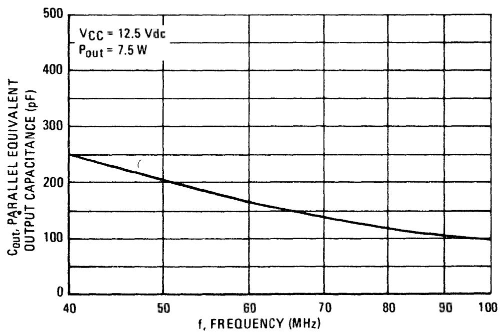



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY



**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF233

## The RF Line

**15 W – 90 MHz**

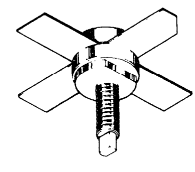
**RF POWER TRANSISTOR**

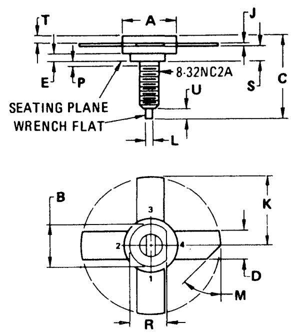
**NPN SILICON**

### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt, mid-band large-signal amplifier applications in industrial and commercial FM equipment operating in the 40 to 100 MHz range.

- Specified 12.5 Volt, 90 MHz Characteristics –
  Output Power = 15 Watts
  Minimum Gain = 10 dB
  Efficiency = 55%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Characterized with Parallel Equivalent Large-Signal Impedance Parameters






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 3.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate Above 25°C | $P_D$<br>– | 50<br>285 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | In-lb |

### THERMAL CHARACTERISTICS

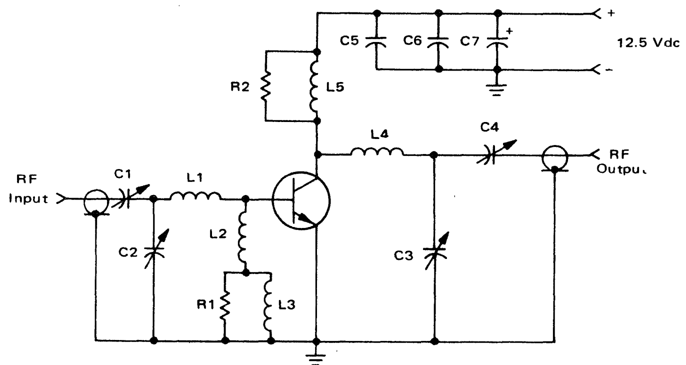
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 3.5 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF amplifiers.
(2) For Repeated Assembly use 5 In. Lb.

ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 100 | 120 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 15 W, f = 90 MHz) | $G_{PE}$ | 10 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 15 W, f = 90 MHz) | $\eta$ | 55 | – | – | % |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 15 W, f = 90 MHz, $T_C \leqslant 25^oC$) | – | VSWR > 30:1 Through All Phase Angles in a 3 Second Interval After Which Devices Will Meet $G_{PE}$ Test Limits | | | |

FIGURE 1 – 90 MHz TEST CIRCUIT SCHEMATIC




C1,C3 9.0-180 pF, ARCO 463
C2,C4 25-280 pF ARCO 464
C5 1000 pF UNELCO
C6 0.01 µF ERIE Disc Ceramic
C7 1.0 µF, 35 Vdc TANTALUM
L1 2 Turns, #18 AWG, 3/8" I.D., 1/4" Long
L2 0.22 µH, 9230-04 MILLER Molded Choke
L3 2.2 µH, 9230-200 MILLER Molded Choke
L4 2 Turns, #18 AWG, 3/8" I.D., 3/8" Long
L5 10 Turns, #16 AWG, Wound On R2.
R1 15 Ohm, 1/2 W, 10% Carbon
R2 68 Ohm, 1 Watt, 10% Carbon
Input/Output Connectors – Type BNC

FIGURE 2 — OUTPUT POWER versus INPUT POWER

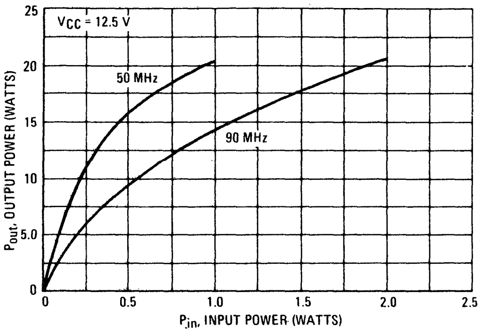



FIGURE 3 — OUTPUT POWER versus FREQUENCY

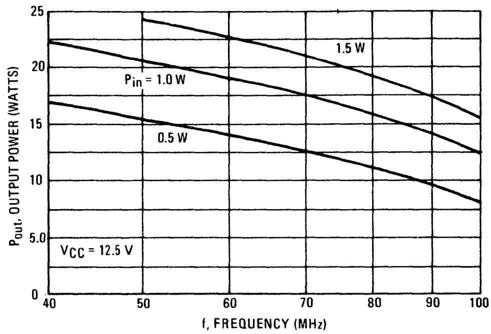



FIGURE 4 — OUTPUT POWER versus SUPPLY VOLTAGE

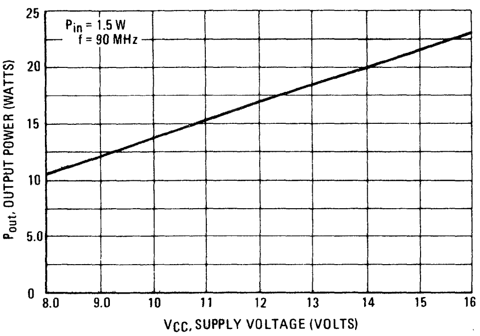
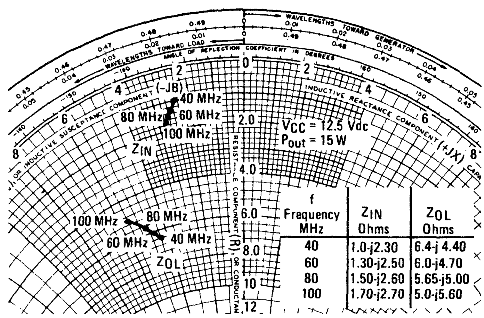



FIGURE 5 — SERIES EQUIVALENT IMPEDANCE




| f Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 40 | 1.0-j2.30 | 6.4-j 4.40 |
| 60 | 1.30-j2.50 | 6.0-j4.70 |
| 80 | 1.50-j2.60 | 5.65-j5.00 |
| 100 | 1.70-j2.70 | 5.0-j5.60 |

FIGURE 6 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

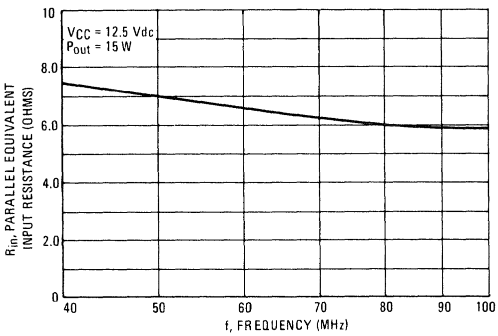



FIGURE 7 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

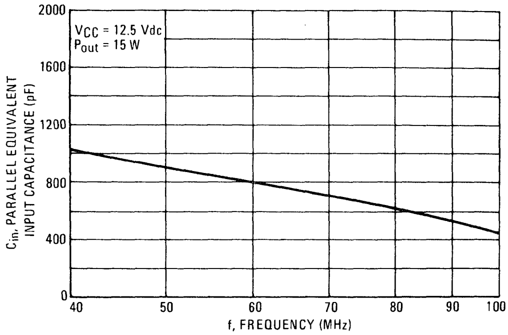



FIGURE 8 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY

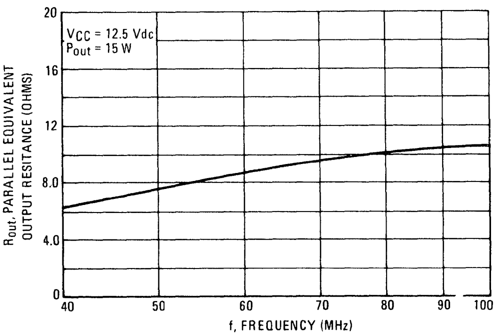
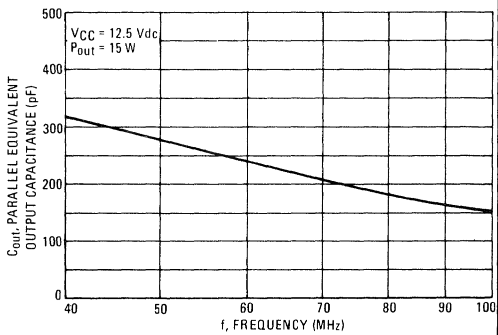



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY



MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

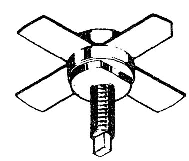
# MRF234

## The RF Line

**25 W – 90 MHz**

**RF POWER TRANSISTOR**

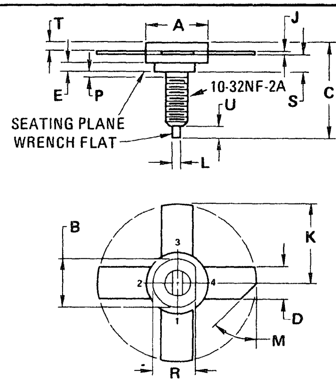
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt, mid-band large-signal amplifier applications in industrial and commercial FM equipment operating in the 40 to 100 MHz range.

- Specified 12.5 Volt, 90 MHz Characteristics –
  Output Power = 25 Watts
  Minimum Gain = 9.5 dB
  Efficiency = 55%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR.
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Characterized with Parallel Equivalent Large-Signal Impedance Parameters




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

NOTE:
1. 145A-10, USE 10-32NF-2A STUD.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 12.45 | 12.95 | 0.490 | 0.510 |
| B | 10.54 | 10.80 | 0.415 | 0.425 |
| C | 19.68 | 22.73 | 0.775 | 0.895 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.83 | – | 0.072 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.65 | 1.90 | 0.065 | 0.075 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 9.73 | 10.06 | 0.383 | 0.396 |
| S | 3.84 | 4.50 | 0.151 | 0.177 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-10

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 70<br>400 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | In. Lb. |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.5 | °C/W |

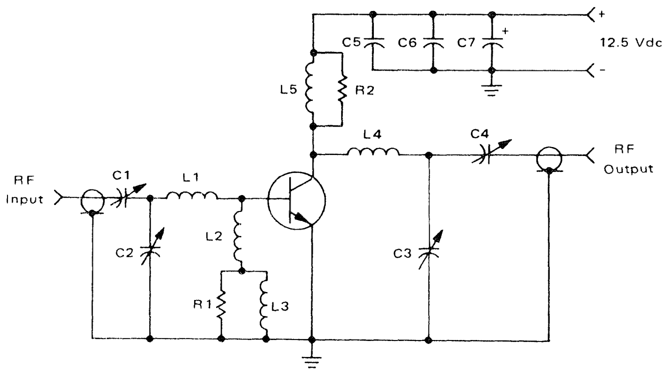
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.

(2) For repeated assembly use 5 In. Lb.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 100 | 120 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 90 MHz) | $G_{PE}$ | 9.5 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 90 MHz) | $\eta$ | 55 | – | – | % |
| Load Mismatch ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 90 MHz, $T_C \leqslant 25°C$) | – | VSWR >30:1 Through All Phase Angles in a 3 Second Interval After Which Devices Will Meet $G_{PE}$ Test Limits. | | | |

**FIGURE 1 – 90 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1,C4 | 5.0-80 pF, ARCO 462 | L3 | 22 µH, 9230-52 MILLER Molded Choke |
| C2,C3 | 25-280 pF, ARCO 464 | L4 | 2 Turns, #14 AWG, 3/8" I.D., 1/4" Long |
| C5 | 1000 pF UNELCO | L5 | 10 Turns, #18 AWG, 1/4" I.D., wound on R2 |
| C6 | 0.047 µF, ERIE disc ceramic | R1 | 15 Ohms, 1/2 W, 10% |
| C7 | 10 µF, 15 Vdc TANTALUM | R2 | 47 Ohm, 1 W Carbon |
| L1 | 1 Turn, #16 AWG, 3/8" I.D., 1/8" Long | | Input/Output Connector – Type BNC |
| L2 | 0.22 µH, 9230-04 MILLER Molded Choke | | |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

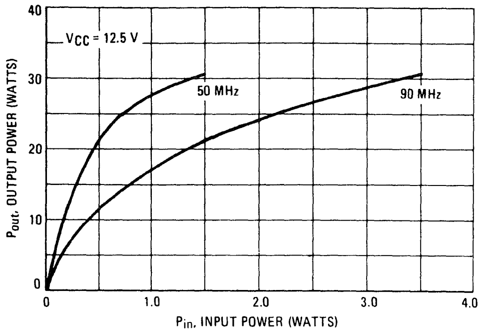



FIGURE 3 – OUTPUT POWER versus FREQUENCY

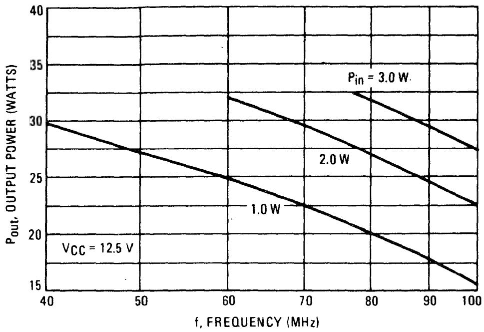



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

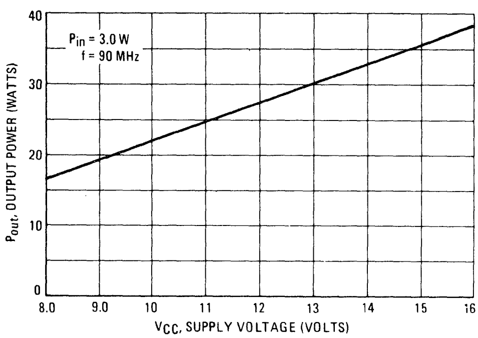
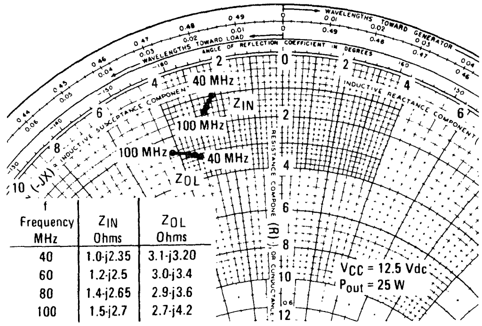



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| f Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 40 | 1.0-j2.35 | 3.1-j3.20 |
| 60 | 1.2-j2.5 | 3.0-j3.4 |
| 80 | 1.4-j2.65 | 2.9-j3.6 |
| 100 | 1.5-j2.7 | 2.7-j4.2 |

FIGURE 6 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

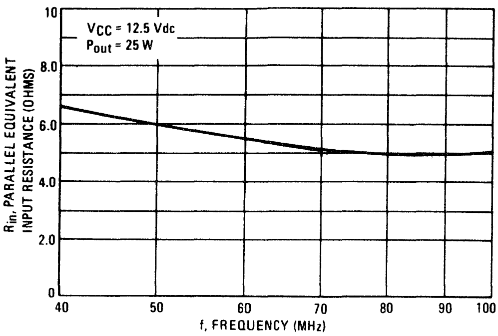



FIGURE 7 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

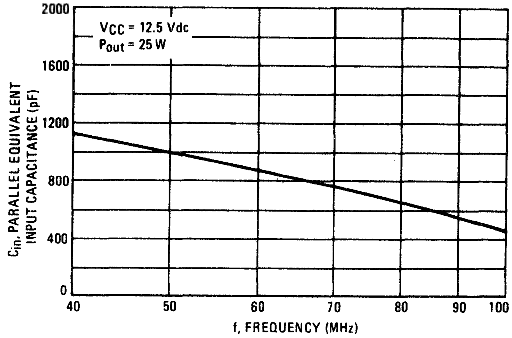



FIGURE 8 – PARALLEL EQUIVALENT OUTPUT RESISTANCE versus FREQUENCY

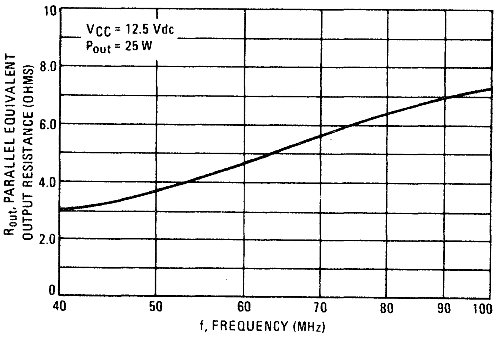
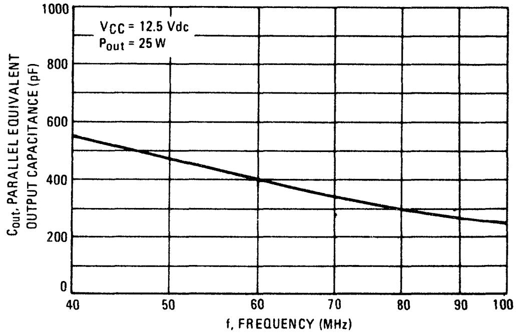
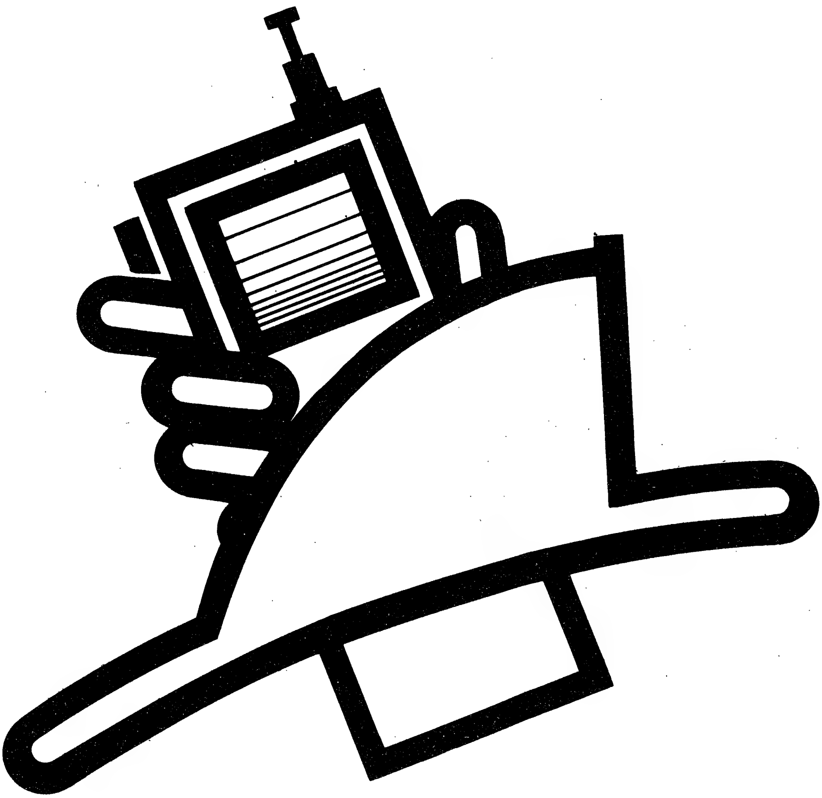



FIGURE 9 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY



# 130-175 MHz, 12.5 Vdc

# CHAPTER 9



**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N4427

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

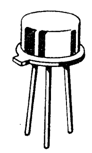
. . . designed for amplifier, frequency multiplier, or oscillator applications in military and industrial equipment. Suitable for use as output driver or pre-driver stages in VHF and UHF equipment.

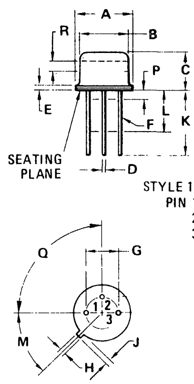
- Specified 175 MHz, 12 Vdc Characteristics —
  Output Power = 1.0 Watt
  Minimum Gain = 10 dB
  Efficiency = 50%

**1 W — 175 MHz**

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**






STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

CASE 79-02
TO-39

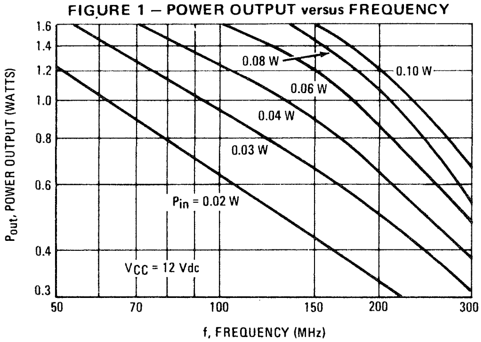
All JEDEC dimensions and notes apply.
Available in TO-46 Package as MRF604

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| *Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| *Collector-Base Voltage | $V_{CB}$ | 40 | Vdc |
| *Emitter-Base Voltage | $V_{EB}$ | 2.0 | Vdc |
| *Collector Current — Continuous | $I_C$ | 400 | mAdc |
| *Base Current — Continuous | $I_B$ | 400 | mAdc |
| Total Device Dissipation @ $T_A = 25^{\circ}C$<br>Derate above 25°C | $P_D$ | 1.0<br>5.71 | Watt<br>mW/°C |
| *Total Device Dissipation @ $T_C = 25^{\circ}C$<br>Derate above 25°C | $P_D$ | 3.5<br>20 | Watts<br>mW/°C |
| *Storage Temperature Range | $T_{stg}$ | -65 to + 200 | °C |

*Indicates JEDEC Registered Data

FIGURE 1 — POWER OUTPUT versus FREQUENCY



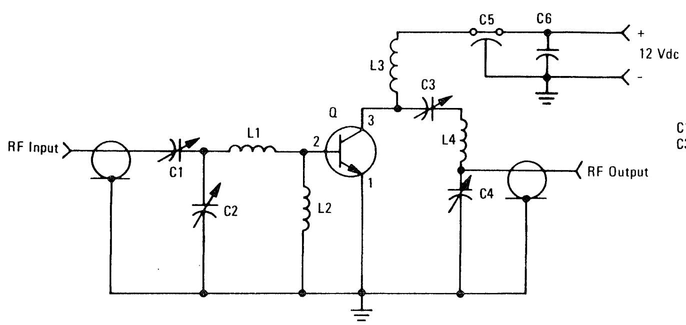

9

## ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| *Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 20 | – | Vdc |
| *Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 10 ohms) | $V_{CER(sus)}$ | 40 | – | Vdc |
| *Collector Cutoff Current ($V_{CE}$ = 12 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | 0.02 | mAdc |
| *Collector Cutoff Current ($V_{CE}$ = 40 Vdc, $V_{BE}$ = −1.5 Vdc)<br>($V_{CE}$ = 12 Vdc, $V_{BE}$ = −1.5 Vdc, $T_C$ = +150°C) | $I_{CEV}$ | –<br>– | 0.1<br>5.0 | mAdc |
| *Emitter Cutoff Current ($V_{EB}$ = 2.0 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| *DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc)<br>($I_C$ = 360 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10<br>5.0 | 200<br>– | – |
| *Collector-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 20 mAdc) | $V_{CE(sat)}$ | – | 0.5 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | |
| *Current-Gain – Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 500 | – | MHz |
| *Output Capacitance ($V_{CB}$ = 12 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 4.0 | pF |
| **FUNCTIONAL TEST** | | | | |
| *Power Input (Figure 1) ($P_{out}$ = 1.0 W, $V_{CC}$ = 12 Vdc, f = 175 MHz) | $P_{in}$ | – | 100 | mW |
| Common-Emitter Amplifier Power Gain ($P_{in}$ = 100 mW, $V_{CC}$ = 12 Vdc, f = 175 MHz) | $G_{pe}$ | 10 | – | dB |
| *Collector Efficiency (Figure 1) ($P_{out}$ = 1.0 W, $V_{CC}$ = 12 Vdc, f = 175 MHz) | $\eta$ | 50 | – | % |

*Indicates JEDEC Registered Data

FIGURE 2 – 175 MHz RF AMPLIFIER CIRCUIT FOR POWER-OUTPUT TEST




C1, C2, C3, and C4: 3-30 pF
C5: 1,000 pF
C6: 0.01 µF
L1: 2 turns No. 16 wire, 3/16" ID, 1/4" long
L2: Ferrite choke, Z = 450 ohms
L3: 2 turns No. 16 wire, 1/4" ID, 1/4" long
L4: 4 turns No. 16 wire, 3/8" ID, 3/8" long
Q: 2N4427

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MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5589

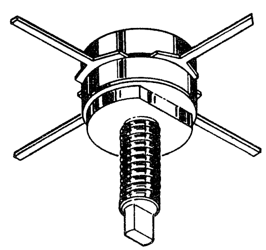
## The RF Line

NPN SILICON
RF POWER
TRANSISTOR

## NPN SILICON RF POWER TRANSISTOR

. . . designed for 13.6 volt, VHF large signal power amplifier applications required in military and industrial equipment operating to 240 MHz.

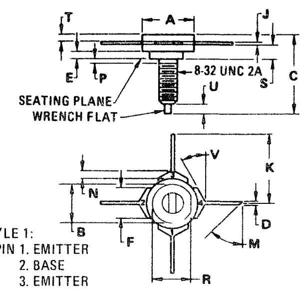
- Low lead inductance stripline package for easier design and increased broadband capability.
- Balanced Emitter Construction for increased Safe Operating Area. The 2N5589 is designed to withstand an Open or Shorted Load at rated Output Power.
- Specified 13.6 Volt, 175 MHz Characteristics –
  Output Power = 3.0 Watts
  Minimum Gain = 8.2 dB
  Efficiency = 50%



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.6 | Adc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 15<br>86 | Watts<br>mW/$^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

*Indicates JEDEC Registered Data.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 1.78 | – | 0.070 | – |
| F | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| M | $45^0$ NOM | | $45^0$ NOM | |
| N | 1.27 | 1.52 | 0.050 | 0.060 |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |
| V | $10^0$ | $20^0$ | $10^0$ | $20^0$ |

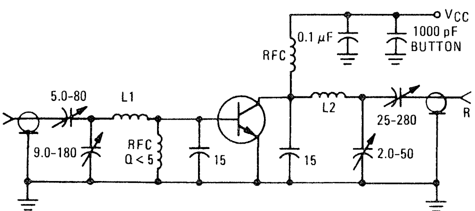
CASE 144B-05

*ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 15 | 30 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Power Input (Figure 1) ($P_{out}$ = 3.0 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $P_{in}$ | – | 0.35 | 0.45 | Watt |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 3.0 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $G_{PE}$ | 8.2 | – | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 3.0 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.
Note 1: Pulsed through 25 mH inductor.

FIGURE 1 – 175 MHz TEST CIRCUIT




All capacitance values in pF unless otherwise indicated
L1 – 1-3/8" length of #14 AWG Wire
L2 – 2 Turns #16 AWG Wire, 1/4" Dia. 1-1/2" Long

## POWER OUTPUT versus FREQUENCY

FIGURE 2

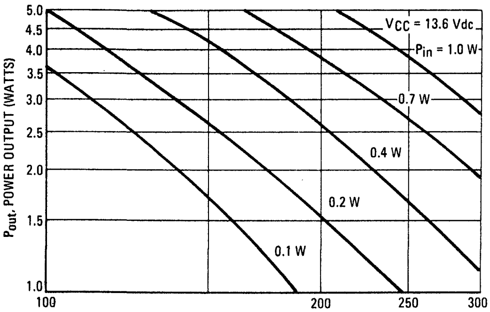



FIGURE 3

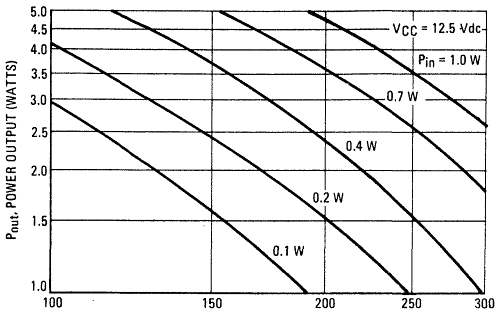



FIGURE 4 – POWER OUTPUT versus POWER INPUT

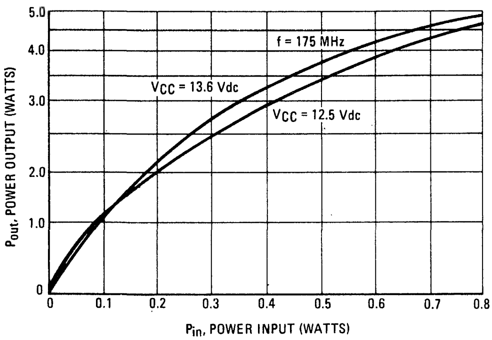
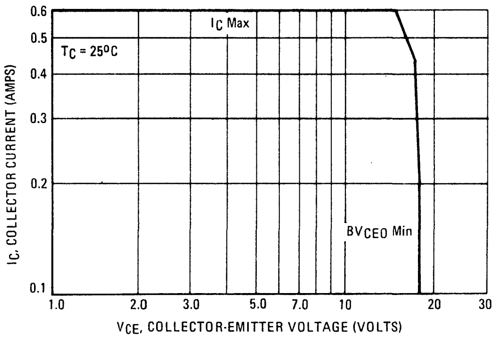



FIGURE 5 – DC SAFE OPERATING AREA




## PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

FIGURE 6

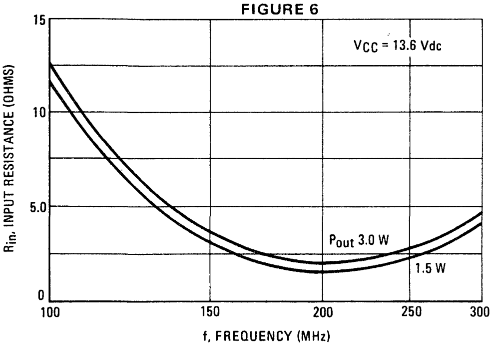
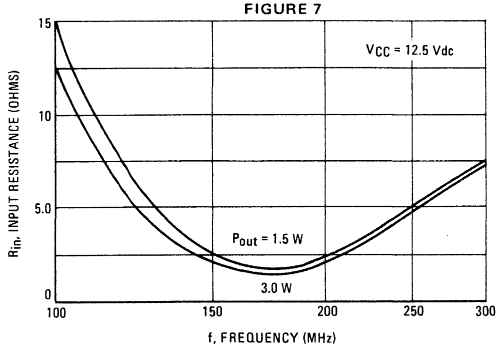



FIGURE 7



## PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

FIGURE 8

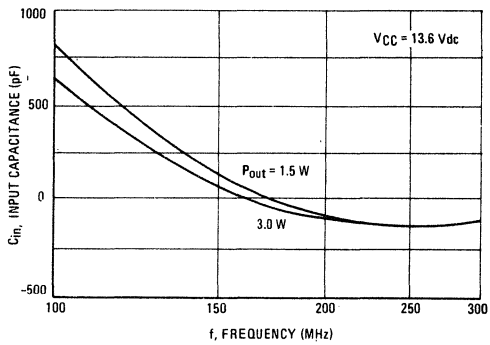
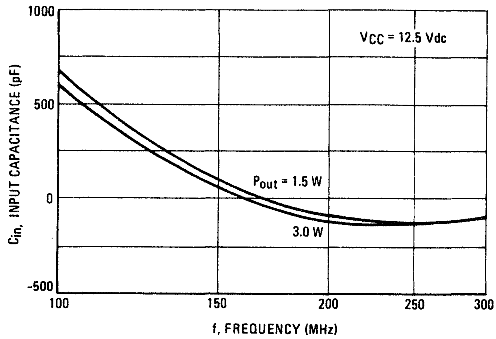



FIGURE 9




## PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

FIGURE 10

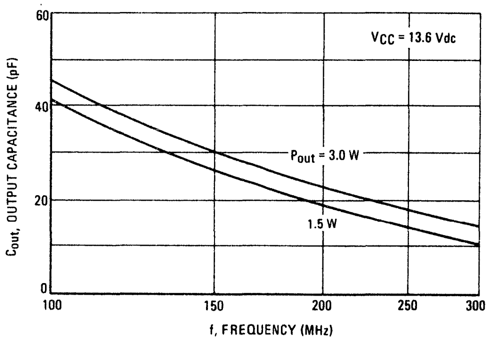
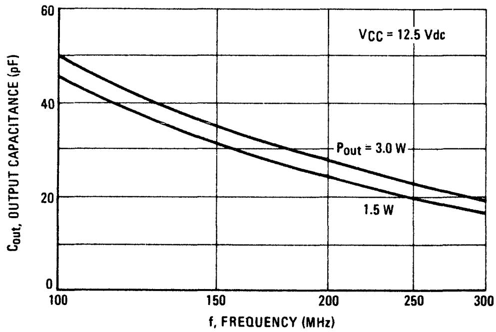



FIGURE 11




## SERIES INPUT IMPEDANCE versus FREQUENCY

FIGURE 12

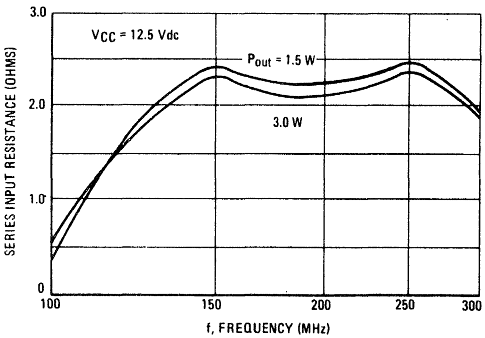
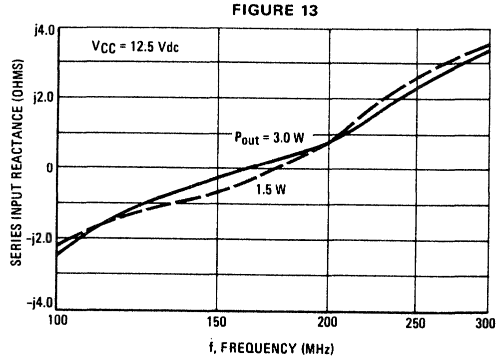



FIGURE 13



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# 2N5590

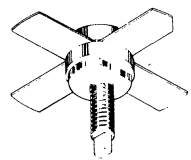
## The RF Line

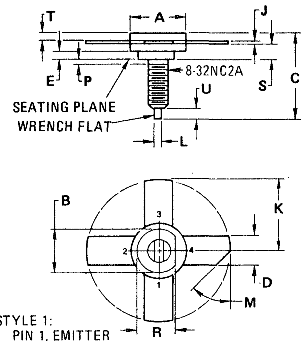
NPN SILICON
RF POWER
TRANSISTOR

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 13.6 volt, VHF large signal power amplifier applications required in military and industrial equipment operating to 240 MHz.

- Low lead inductance stripline package for easier design and increased broadband capability.
- Balanced Emitter Construction for increased Safe Operating Area. The 2N5590 is designed to withstand an Open or Shorted Load at rated Output Power.
- Specified 13.6 Volt, 175 MHz Characteristics –
  Output Power = 10 Watts
  Minimum Gain = 5.2 dB
  Efficiency = 50%






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | $45^0$ NOM | | $45^0$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.0 | Adc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 30<br>171 | Watts<br>$mW/^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

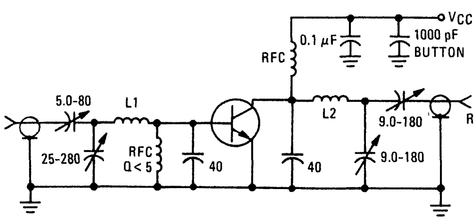
*Indicates JEDEC Registered Data.

*ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| *Collector-Emitter Sustaining Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO(sus)}$ | 18 | – | – | Vdc |
| *Collector-Emitter Sustaining Voltage (Note 1) ($I_C$ = 200 mAdc, $R_{BE}$ = 0) | $BV_{CES(sus)}$ | 36 | – | – | Vdc |
| *Emitter-Base Breakdown Voltage ($I_E$ = 2.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| *DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| *Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 35 | 70 | pF |
| **FUNCTIONAL TEST** | | | | | |
| *Power Input (Figure 1) ($P_{out}$ = 10 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $P_{in}$ | – | – | 3.0 | Watts |
| *Common-Emitter Amplifier Power Gain (Figure 1 ($P_{out}$ = 10 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $G_{PE}$ | 5.2 | – | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 10 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.
Note 1: Pulsed through 25 mH inductor.

FIGURE 1 – 175 MHz TEST CIRCUIT




All capacitance values in pF unless otherwise indicated
L1 – 1-3/8" length of #14 AWG Wire
L2 – 1 Turn #14 AWG Wire, 3/8" Dia. 1-1/2" Long

## POWER OUTPUT versus FREQUENCY

FIGURE 2

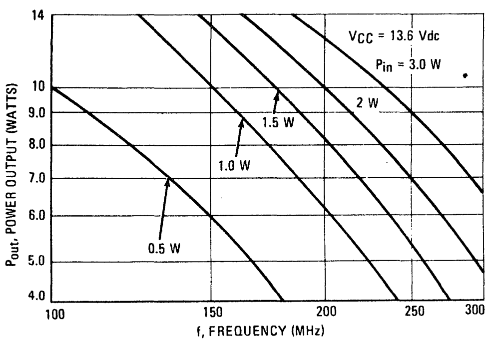



FIGURE 3

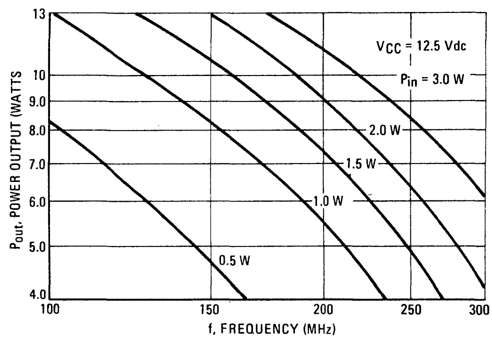



FIGURE 4 – POWER OUTPUT versus POWER INPUT

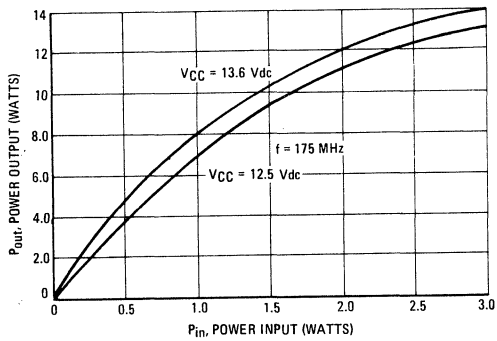
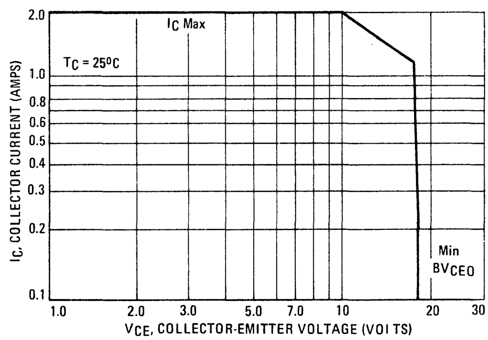



FIGURE 5 – DC SAFE OPERATING AREA




## PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

FIGURE 6

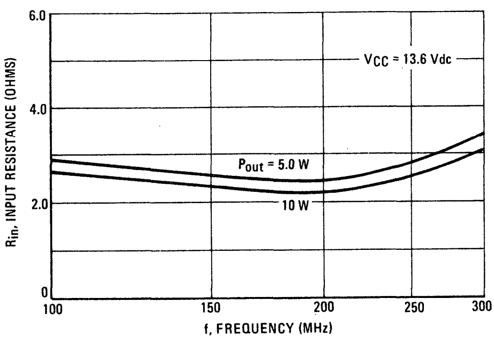
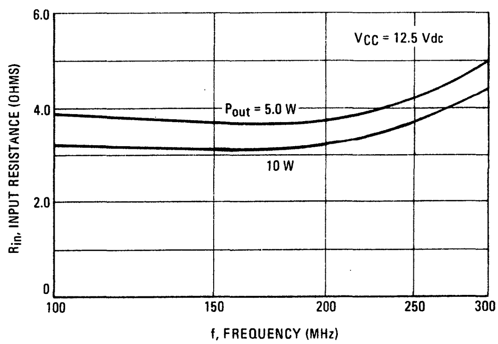



FIGURE 7



## PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

FIGURE 8

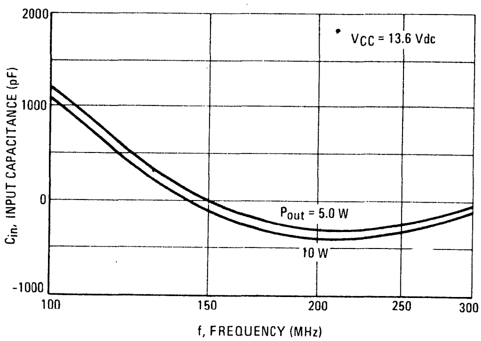
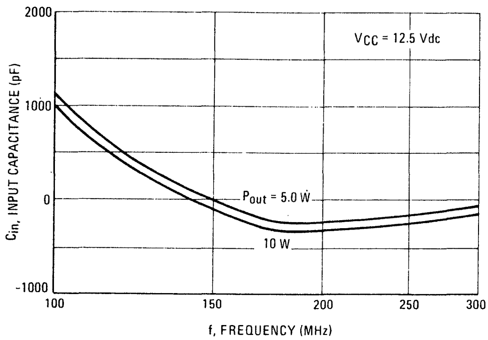



FIGURE 9




## PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

FIGURE 10

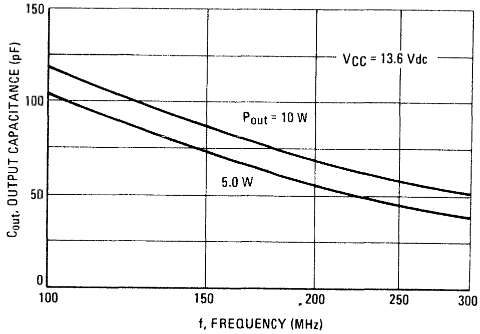
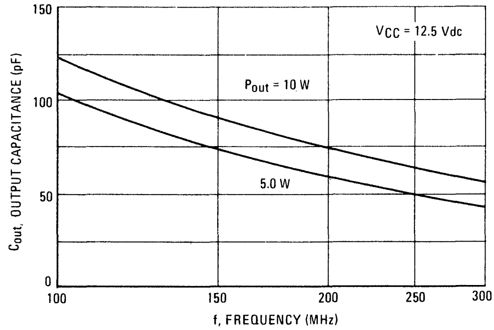



FIGURE 11




## SERIES INPUT IMPEDANCE versus FREQUENCY

FIGURE 12

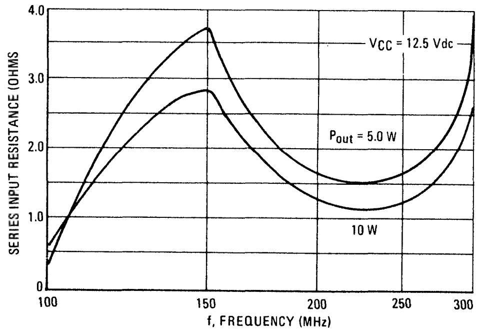
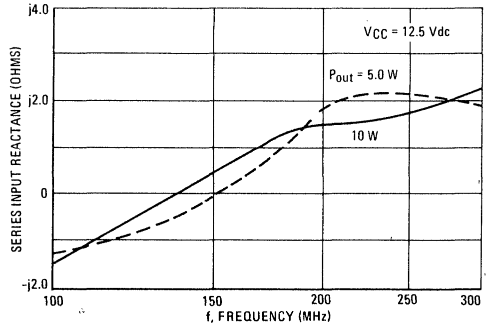



FIGURE 13



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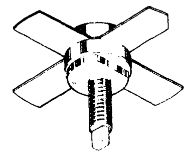
# 2N5591

## The RF Line

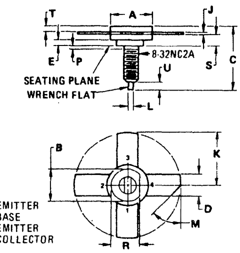
NPN SILICON
RF POWER
TRANSISTOR



## NPN SILICON RF POWER TRANSISTOR

. . . designed for 13.6 volt, VHF large signal power amplifier applications required in military and industrial equipment operating to 240 MHz.

- Low lead inductance stripline package for easier design and increased broadband capability.
- Balanced Emitter Construction for increased Safe Operating Area. The 2N5591 is designed to withstand an Open or Shorted Load at rated Output Power.
- Specified 13.6 Volt. 175 MHz Characteristics –
  Output Power = 25 Watts
  Minimum Gain = 4.4 dB
  Efficiency = 50%




STYLE 1.
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

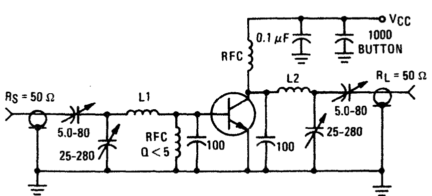
145A-09

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 70<br>400 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

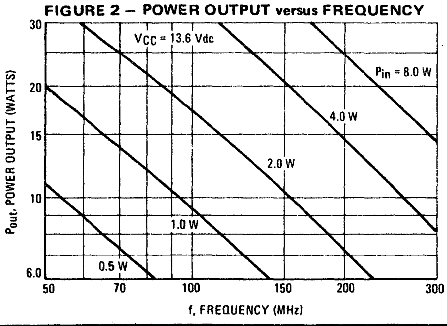
*Indicates JEDEC Registered Data.

FIGURE 1 – 175 MHz TEST CIRCUIT




ALL CAPACITORS IN pF UNLESS OTHERWISE INDICATED
L1 – #14 AWG STRAIGHT WIRE, 1-3/8" LONG
L2 – 1 TURN #14 AWG WIRE, 3/8" DIA. 1-1/2" LONG

FIGURE 2 – POWER OUTPUT versus FREQUENCY



**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| *Collector-Emitter Sustaining Voltage (Note 1) ($I_C$ = 200 mAdc, $I_B$ = 0) | $BV_{CEO(sus)}$ | 18 | – | – | Vdc |
| *Collector-Emitter Sustaining Voltage (Note 1) ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | $BV_{CES(sus)}$ | 36 | – | – | Vdc |
| *Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| ***ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| ***DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{ob}$ | – | 90 | 120 | pF |
| ***FUNCTIONAL TEST** | | | | | |
| Power Input (Figure 1) ($P_{out}$ = 25 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $P_{in}$ | – | – | 9.0 | Watts |
| Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 25 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $G_{PE}$ | 4.4 | – | – | dB |
| Collector Efficiency (Figure 1) ($P_{out}$ = 25 W, $V_{CE}$ = 13.6 Vdc, f = 175 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.
Note 1: Pulsed through 25 mH inductor.

**FIGURE 3 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY**

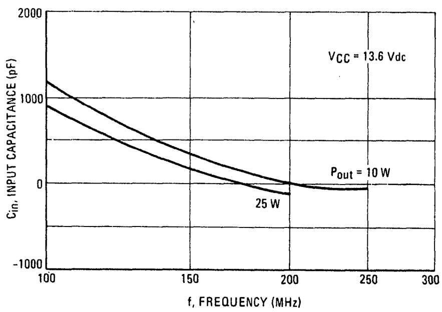



**FIGURE 4 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY**

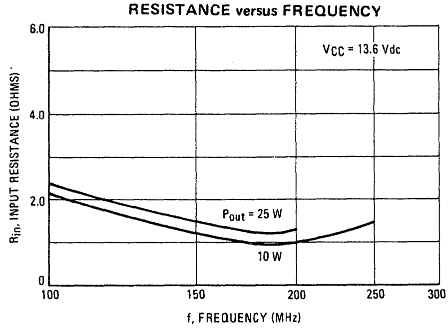



**FIGURE 5 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY**

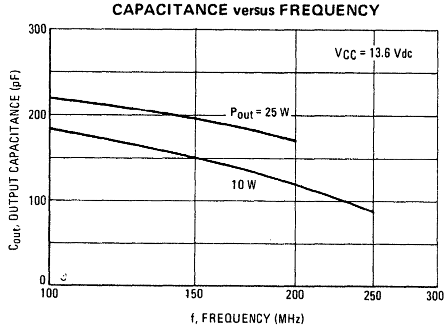
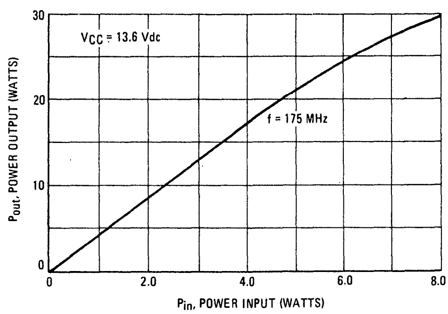



**FIGURE 6 – POWER OUTPUT versus POWER INPUT**



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Semiconductors
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# 2N6080

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

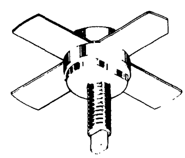
. . . designed for 12.5 Volt VHF large-signal power amplifier applications required in military and industrial equipment operating to 300 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 4.0 W
  Minimum Gain = 12 dB
  Efficiency = 50%
- Characterized with Series Equivalent Large-Signal Impedance Parameters

4.0 W – 175 MHz

RF POWER
TRANSISTOR

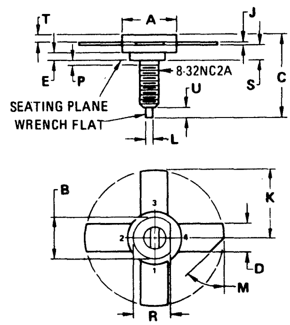
NPN SILICON



*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (2)<br>Derate above $25^oC$ | $P_D$ | 12<br>68.5 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |
| Stud Torque (1) | – | 6.5 | in. lb. |

*Indicates JEDEC Registered Data.
(1) For repeated assembly use 5 in lb.
(2) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

145A-09

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | – | 5.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.25 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 0.25 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 15 | 20 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 4.0 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 12 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 4.0 W, $V_{CC}$ = 12.5 Vdc, f - 175 MHz) | $\eta$ | 50 | – | – | % |

*Indicates JEDEC Registered Data.

**FIGURE 1 – 175 MHz TEST CIRCUIT**

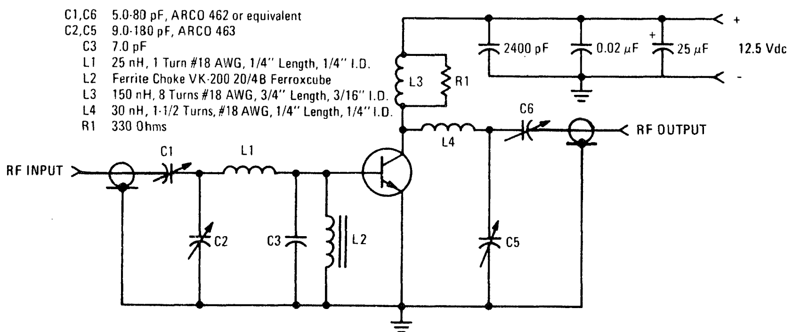


FIGURE 2 – OUTPUT POWER versus INPUT POWER

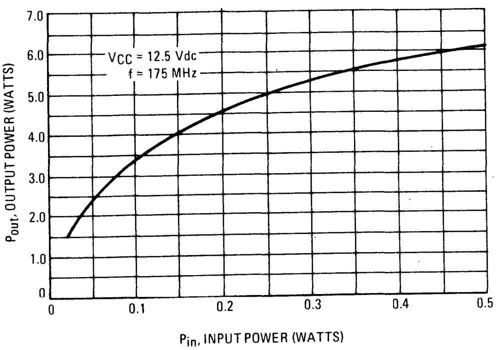



FIGURE 3 – OUTPUT POWER versus FREQUENCY

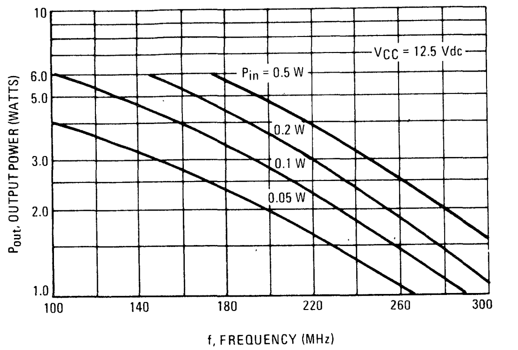



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

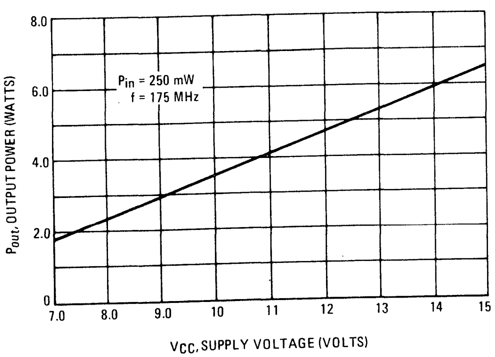
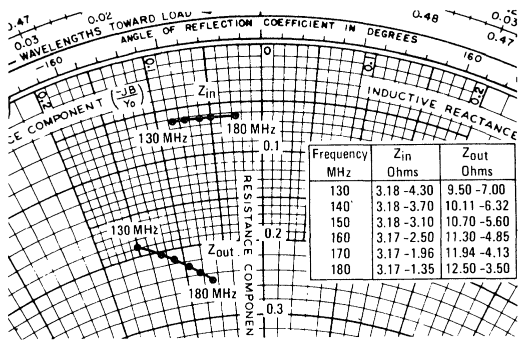



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{out}$ Ohms |
|---|---|---|
| 130 | 3.18 -4.30 | 9.50 -7.00 |
| 140 | 3.18 -3.70 | 10.11 -6.32 |
| 150 | 3.18 -3.10 | 10.70 -5.60 |
| 160 | 3.17 -2.50 | 11.30 -4.85 |
| 170 | 3.17 -1.96 | 11.94 -4.13 |
| 180 | 3.17 -1.35 | 12.50 -3.50 |

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6081
# MRF221

## The RF Line

### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt VHF large-signal power amplifier applications required in commercial and industrial equipment operating to 300 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 15 W
  Minimum Gain = 6.3 dB
  Efficiency = 60%
- Characterized with Series Equivalent Large-Signal Impedance Parameters

15 W – 175 MHz

RF POWER TRANSISTORS

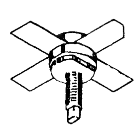
NPN SILICON

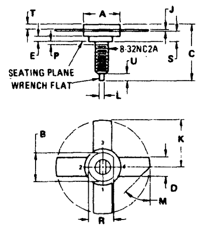
### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.5 | Adc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above $25^{\circ}C$ | $P_D$ | 31<br>177 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | in. lb. |

*Indicates JEDEC Registered Data for 2N6081.
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.
(2) For repeated assembly use 5 in. lb.

2N6081



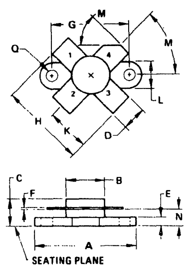


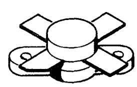

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

MRF221



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

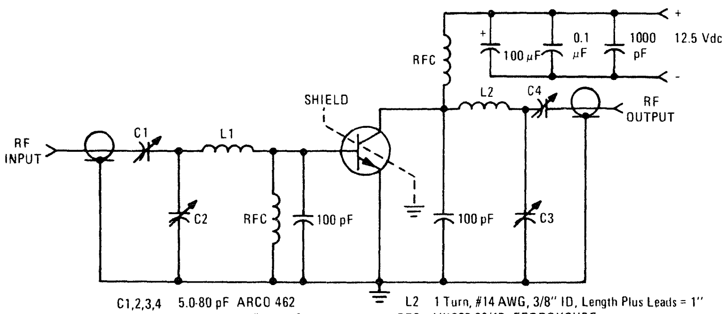
CASE 211-07

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | – | 8.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 0.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 70 | 85 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 15 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 6.3 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 15 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |

*Indicates JEDEC Registered Data for 2N6081.

FIGURE 1 – 175 MHz TEST CIRCUIT




C1,2,3,4 5.0-80 pF ARCO 462
L1 Straight Wire, #14 AWG, 1-3/8" Long
L2 1 Turn, #14 AWG, 3/8" ID, Length Plus Leads = 1"
RFC VK200-20/4B, FERROXCUBE.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

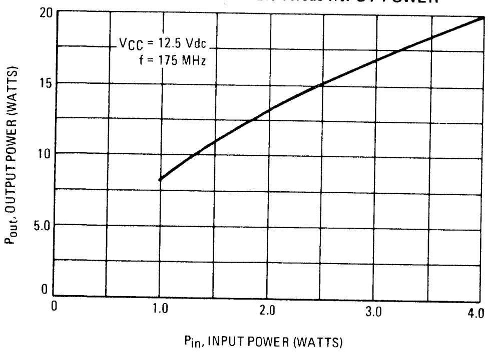



FIGURE 3 – OUTPUT POWER versus FREQUENCY

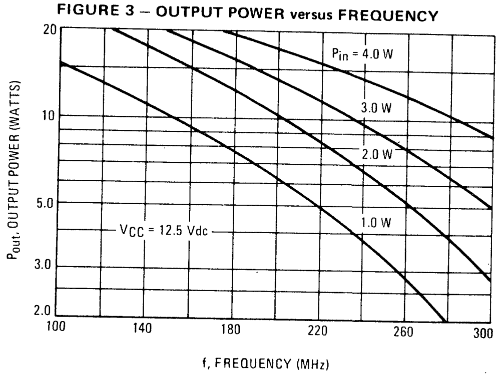



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

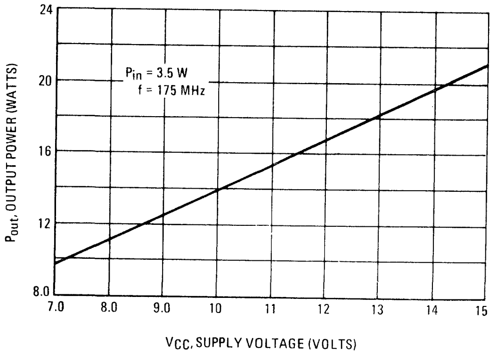
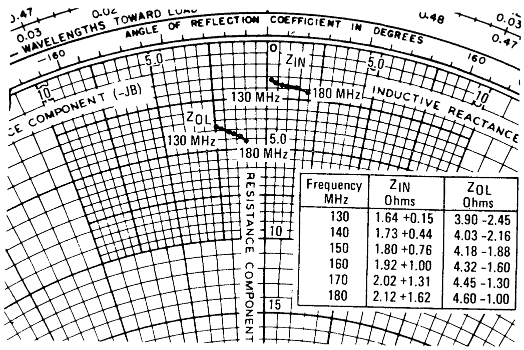



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 130 | 1.64 +0.15 | 3.90 -2.45 |
| 140 | 1.73 +0.44 | 4.03 -2.16 |
| 150 | 1.80 +0.76 | 4.18 -1.88 |
| 160 | 1.92 +1.00 | 4.32 -1.60 |
| 170 | 2.02 +1.31 | 4.45 -1.30 |
| 180 | 2.12 +1.62 | 4.60 -1.00 |

MOTOROLA
Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6082
# MRF222

## The RF Line

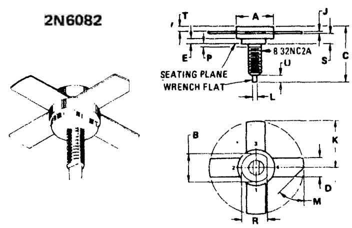
25 W — 175 MHz
RF POWER
TRANSISTORS
NPN SILICON

### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt VHF large-signal amplifier applications required in commercial and industrial equipment operating to 300 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics —
  Output Power = 25 W
  Minimum Gain = 6.2 dB
  Efficiency = 65%

2N6082

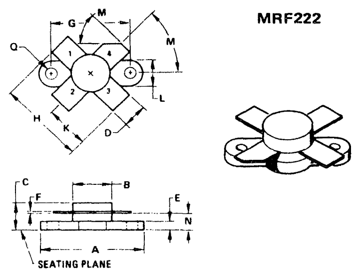



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.64 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

MRF222




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

CASE 211-07

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 75^{\circ}C$(2)<br>Derate above 25°C | $P_D$ | 65<br>0.52 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque(1) | — | 6.5 | in. lb. |

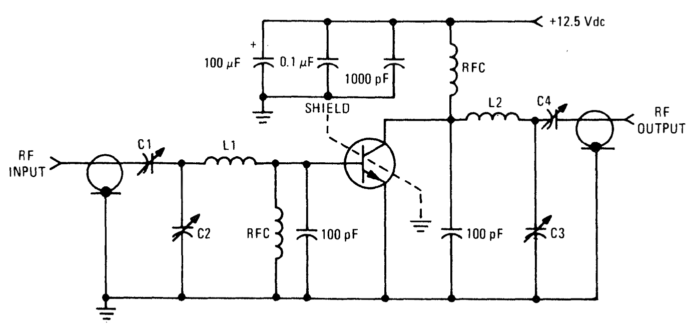
*Indicates JEDEC Registered Data for 2N6082.
(1)For Repeated Assembly Use 5 in. lb.
(2)These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 15 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 110 | 130 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 25 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 6.2 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 25 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 65 | – | – | % |

*Indicates JEDEC Registered Data for 2N6082.

**FIGURE 1 – 175 MHz TEST CIRCUIT**




C1,2,3,4 5.0-80 pF ARCO 462
L1 Straight Wire, #14 AWG, 1-3/8" Long
L2 1 Turn, #14 AWG, 3/8" ID, Length Plus Leads = 1"
RFC VK200-20/4B, FERROXCUBE.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

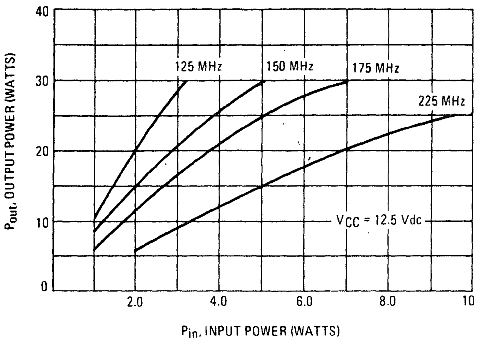



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

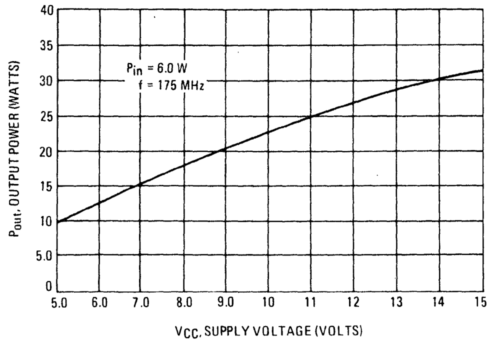
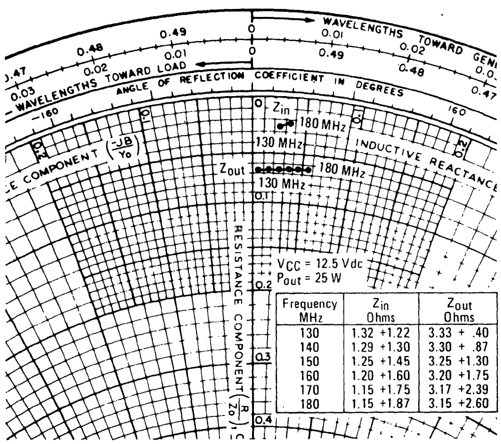



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{out}$ Ohms |
|---|---|---|
| 130 | 1.32 +1.22 | 3.33 + .40 |
| 140 | 1.29 +1.30 | 3.30 + .87 |
| 150 | 1.25 +1.45 | 3.25 +1.30 |
| 160 | 1.20 +1.60 | 3.20 +1.75 |
| 170 | 1.15 +1.75 | 3.17 +2.39 |
| 180 | 1.15 +1.87 | 3.15 +2.60 |

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6083
# MRF223

## The RF Line

30 W – 175 MHz
RF POWER
TRANSISTORS
NPN SILICON

### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt VHF large-signal amplifier applications required in commercial and industrial equipment operating to 300 MHz.

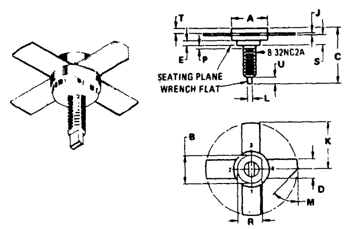
- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 30 W
  Minimum Gain = 5.7 dB
  Efficiency = 65%

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 75^{\circ}C$(2)<br>Derate above $25^{\circ}C$ | $P_D$ | 65<br>0.52 | Watts<br>$W/^{\circ}C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^{\circ}C$ |
| Stud Torque(1) | – | 6.5 | in. lb. |

*Indicates JEDEC Registered Data for 2N6083.
(1) For Repeated Assembly Use 5 in. lb.
(2) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**2N6083**

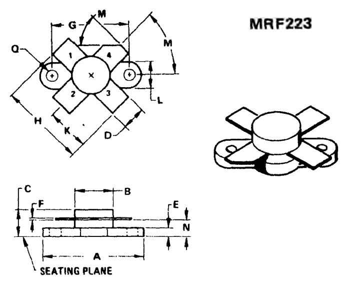



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.386 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

**MRF223**




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

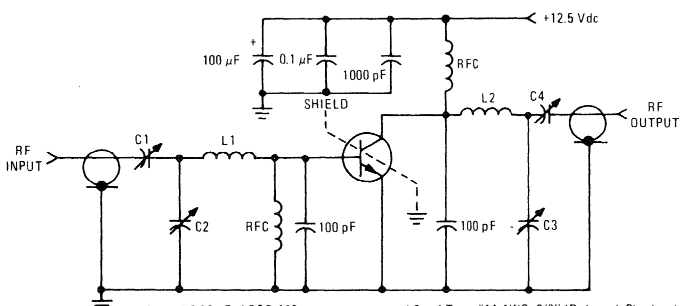
CASE 211-07

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 15 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 110 | 130 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 30 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 5.7 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 30 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 65 | – | – | % |

*Indicates JEDEC Registered Data for 2N6083.

**FIGURE 1 – 175 MHz TEST CIRCUIT**




C1,2,3,4 5.0-80 pF ARCO 462
L1 Straight Wire, #14 AWG, 1-3/8" Long
L2 1 Turn, #14 AWG, 3/8" ID, Length Plus Leads = 1"
RFC VK200-20/4B, FERROXCUBE.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

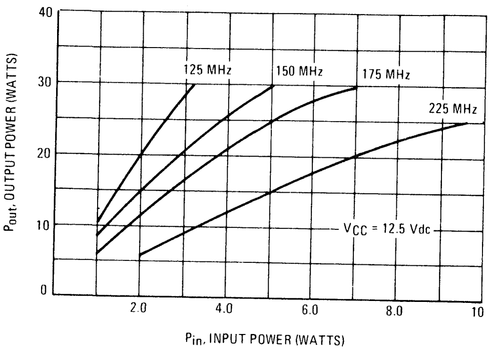



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

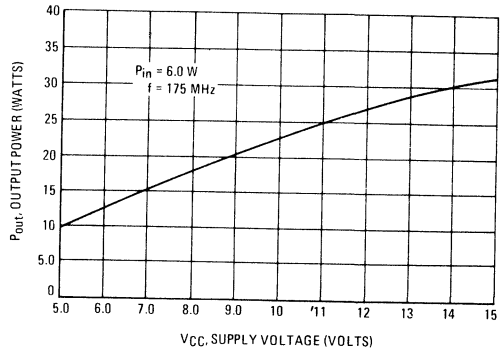
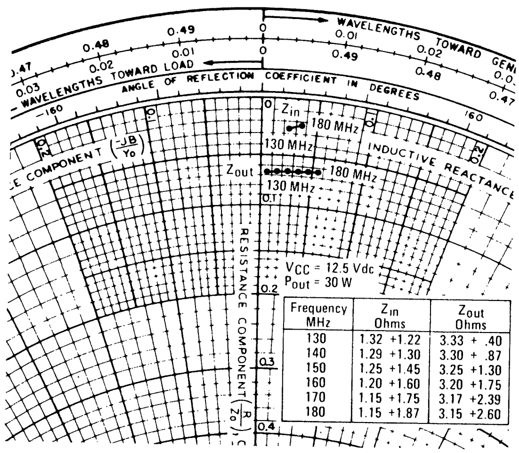



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | Zin Ohms | Zout Ohms |
|---|---|---|
| 130 | 1.32 +1.22 | 3.33 + .40 |
| 140 | 1.29 +1.30 | 3.30 + .87 |
| 150 | 1.25 +1.45 | 3.25 +1.30 |
| 160 | 1.20 +1.60 | 3.20 +1.75 |
| 170 | 1.15 +1.75 | 3.17 +2.39 |
| 180 | 1.15 +1.87 | 3.15 +2.60 |

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6084
# MRF224

## The RF Line

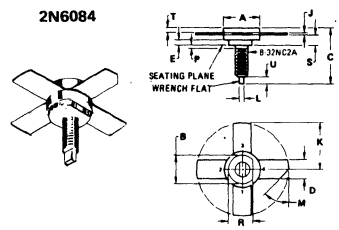
**40 W – 175 MHz**
**RF POWER**
**TRANSISTORS**
**NPN SILICON**

## NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt VHF large-signal amplifier applications required in commercial and industrial equipment operating to 300 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 40 W
  Minimum Gain = 4.5 dB
  Efficiency = 70%

**2N6084**

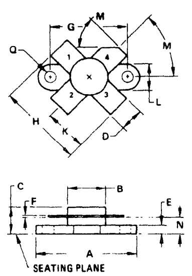


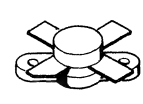

STYLE 1
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

**MRF224**



| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.64 | 24.89 | 0.970 | 0.980 |
| B | 9.40 | 9.91 | 0.370 | 0.390 |
| C | 5.82 | 7.14 | 0.229 | 0.281 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 2.16 | 2.67 | 0.085 | 0.105 |
| F | 0.10 | 0.15 | 0.004 | 0.006 |
| G | 18.29 | 18.54 | 0.720 | 0.730 |
| H | 20.07 | 20.57 | 0.790 | 0.810 |
| K | 10.03 | 10.29 | 0.395 | 0.405 |
| L | 6.22 | 6.48 | 0.245 | 0.255 |
| M | 40° | 50° | 40° | 50° |
| N | 3.81 | 4.57 | 0.150 | 0.180 |
| Q | 2.87 | 3.30 | 0.113 | 0.130 |

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

CASE 211-07

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 6.0 | Adc |
| Total Device Dissipation @ $T_C = 75^{\circ}C$(2)<br>Derate above 25°C | $P_D$ | 80<br>0.64 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque(1) | – | 6.5 | in. lb. |

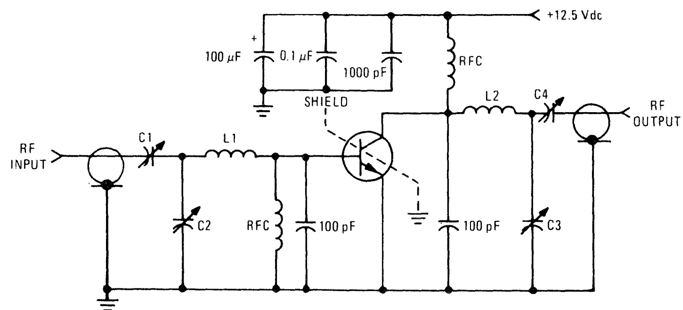
*Indicates JEDEC Registered Data for 2N6084.
(1)For Repeated Assembly Use 5 in. lb.
(2)These devices are designed for RF operation. The total device dissipation rating applie only when the devices are operated as RF amplifiers.

***ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = +55°C) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 2.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 170 | 200 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 4.5 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 70 | – | – | % |

*Indicates JEDEC Registered Data for 2N6084.

FIGURE 1 – 175 MHz TEST CIRCUIT




C1,2,3,4  5.0-80 pF ARCO 462
L1  Straight Wire, #14 AWG, 1-3/8" Long
L2  1 Turn, #14 AWG, 3/8" ID, Length Plus Leads = 1"
RFC  VK200-20/4B, FERROXCUBE.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

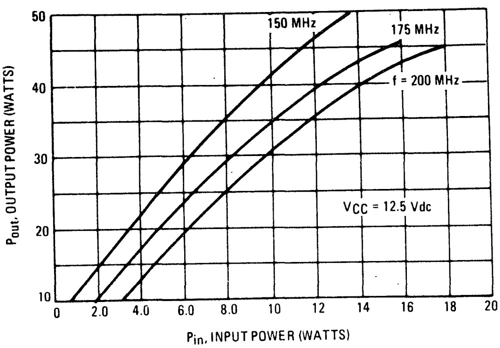



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

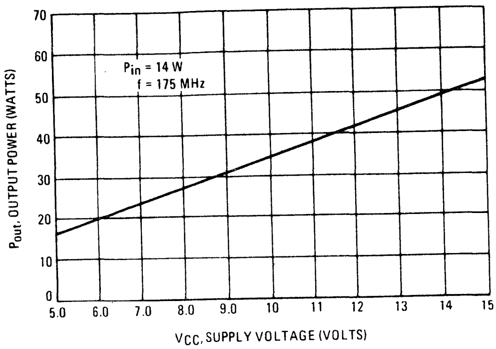
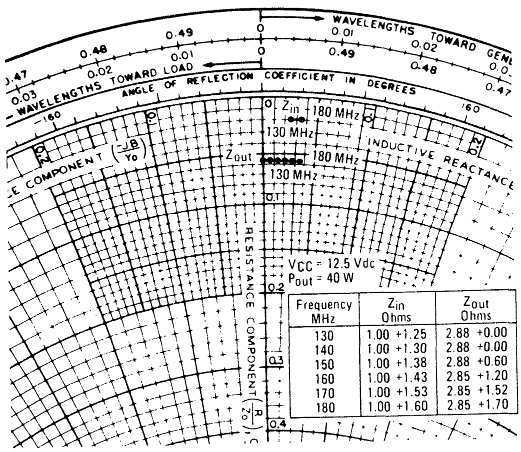



FIGURE 4 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | Zin Ohms | Zout Ohms |
|---|---|---|
| 130 | 1.00 +1.25 | 2.88 +0.00 |
| 140 | 1.00 +1.30 | 2.88 +0.00 |
| 150 | 1.00 +1.38 | 2.88 +0.60 |
| 160 | 1.00 +1.43 | 2.85 +1.20 |
| 170 | 1.00 +1.53 | 2.85 +1.52 |
| 180 | 1.00 +1.60 | 2.85 +1.70 |

# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6255

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

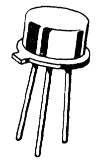
. . . designed for 12.5 Volt VHF driver amplifier applications required in industrial and commercial FM equipment.

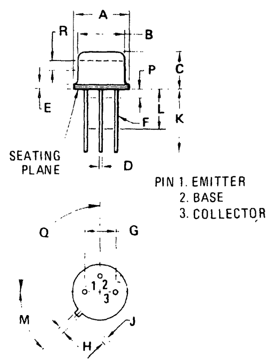
- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 3.0 Watts
  Minimum Gain = 7.8 dB
  Efficiency = 50%

**3.0 W – 175 MHz**

**RF POWER TRANSISTOR**

**NPN SILICON**






PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

### *MAXIMUM RATINGS

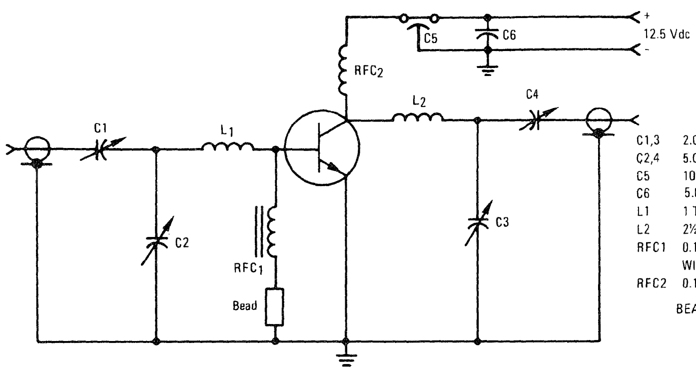
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ | $P_D$ | 5.0 | Watts |
| Derate above 25°C | | 28.5 | mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.
This device is designed for RF operation. The total device dissipation applies only when the device is operated as an RF amplifier.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | $I_{CES}$ | – | – | 5.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.25 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 15 | 20 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 3.0 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 7.8 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 3.0 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 50 | – | – | % |

FIGURE 1 – 175 MHz CIRCUIT




C1,3 2.0-50 pF ARCO 461 ELMENCO
C2,4 5.0-80 pF ARCO 462 ELMENCO
C5 1000 pF FEED THRU
C6 5.0 μF
L1 1 TURN #18 AWG ¼" I.D.
L2 2½ TURNS #18 AWG ¼" I.D.
RFC1 0.15 μH MOLDED CHOKE WITH BEAD ON GROUND LEG
RFC2 0.15 μH MOLDED CHOKE

BEAD IS FERROXCUBE 56-570-65/3B

FIGURE 2 – OUTPUT POWER versus INPUT POWER

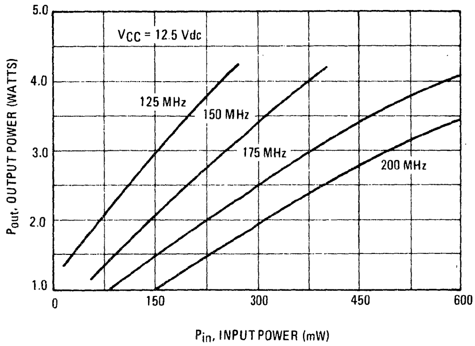



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

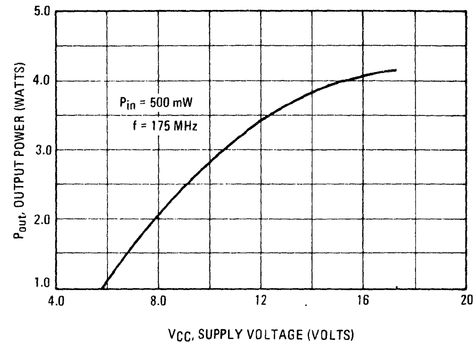



FIGURE 4 – COLLECTOR LOAD versus FREQUENCY

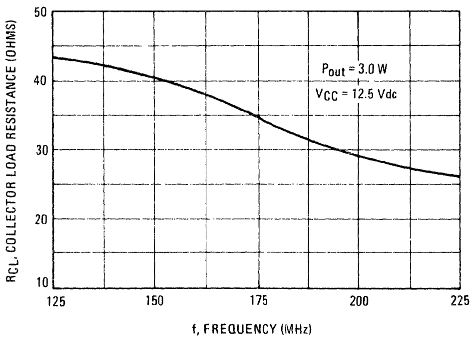



FIGURE 5 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

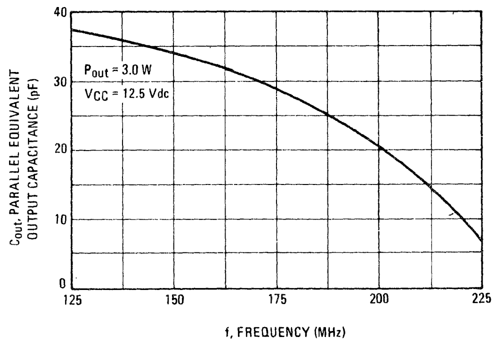



FIGURE 6 – PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

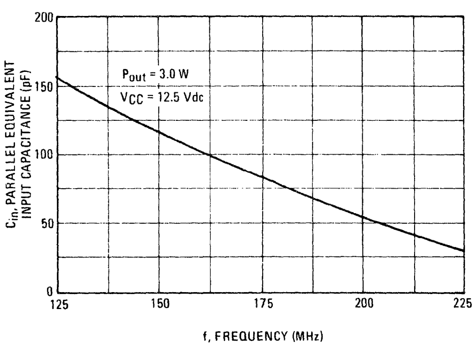
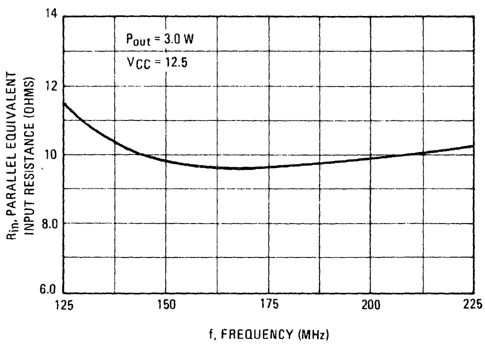



FIGURE 7 – PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

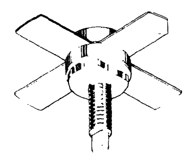
# MRF212

## The RF Line

10 W—175 MHz

RF POWER
TRANSISTOR

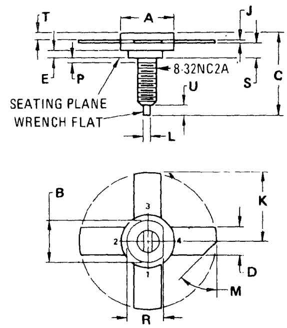
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 volt VHF large-signal power amplifier applications required in commercial and industrial equipment operating to 300 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 10 Watts
  Minimum Gain = 9.0 dB
  Efficiency = 50%




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.0 | Adc |
| Total Device Dissipation @ $T_A$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 37.5<br>0.214 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 4.67 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

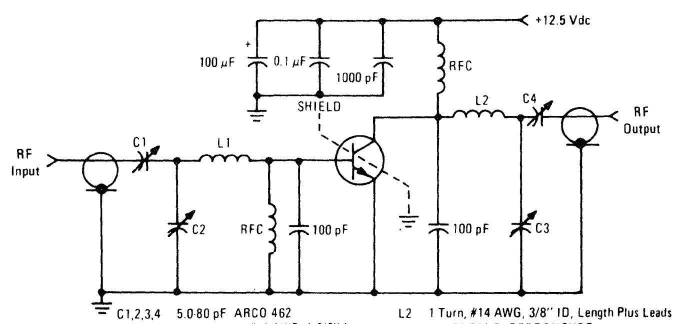
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 15 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 250 mA, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | 50 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 35 | 50 | pF |
| **FUNCTIONAL TESTS (FIGURE 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, f = 175 MHz) | $G_{PE}$ | 9.0 | 11 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, f = 175 MHz) | $\eta$ | 50 | | – | % |

**SERIES EQUIVALENT INPUT/OUTPUT IMPEDANCE**

($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, f = 175 MHz)

| $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|
| 1.74 – j3.93 | 5.86 – j7.37 |

**FIGURE 1 – 175 MHz TEST CIRCUIT**




C1,2,3,4 5.0-80 pF ARCO 462
L1 Straight Wire, #14 AWG, 1-3/8" Long
L2 1 Turn, #14 AWG, 3/8" ID, Length Plus Leads = 1"
RFC VK200-20/4B, FERROXCUBE.

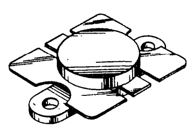
MOTOROLA Semiconductor Products Inc.

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF215

## The RF Line

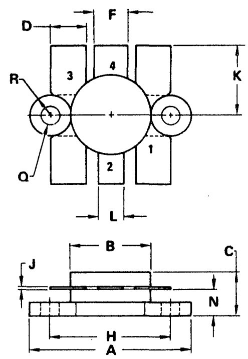
20 W – 175 MHz
CONTROLLED Q
RF POWER
TRANSISTOR
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . .designed for 12.5 Volt VHF large-signal amplifier applications in industrial and commercial FM equipment operating to 175 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 20 Watts
  Minimum Gain = 8.2 dB
  Efficiency = 60%
- 100% Tested for Load Mismatch at all Phase Angles with 20:1 VSWR
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broad Band Operation




STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

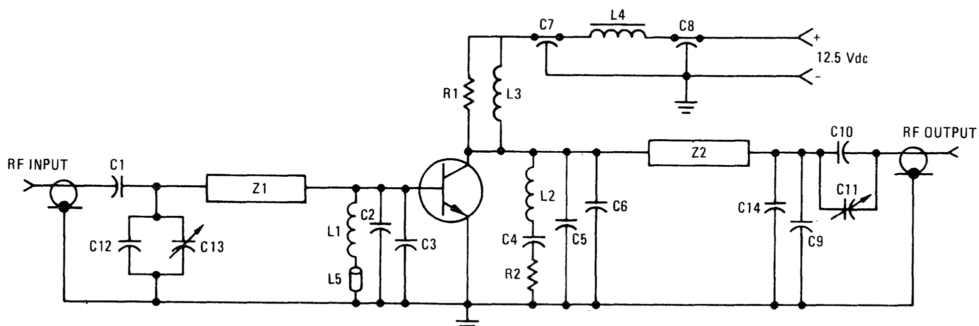
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.5 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 31<br>177 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as class B or C RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | | | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | | | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | | | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | $I_{CES}$ | | | 8.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 70 | 85 | pF |
| **FUNCTIONAL TEST** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 8.2 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |
| Load Mismatch ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz VSWR = 20:1, all phase angles) | – | No Degradation in Output Power | | | |

**FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC**




| | |
|---|---|
| C1,C12 | 15 pF UNDERWOOD |
| C2,C3 | 40 pF UNDERWOOD |
| C4 | 0.1 µF, 100 V, ERIE |
| C5,C6,C10,C14 | 10 pF UNDERWOOD |
| C7,C8 | 680 pF ALLEN BRADLEY Feedthrough |
| C9 | 25 pF UNDERWOOD |
| C11,C13 | 1.0-10 pF JOHANSEN Type 3201 |
| L1 | 0.15 µH Choke |
| L2 | 2 Turns, #24 AWG, 1/8" ID |
| L3 | 6 Turns, #20 AWG, on 390 Ohm, 2 W Resistor |
| L4 | Ferrite Choke, FERROXCUBE VK-200-10-4B |
| L5 | Ferrite Bead, FERROXCUBE 56-590-65-3B |
| R1 | 390 Ohm, 1/2 W, 10% |
| R2 | 2.7 Ohm, 1/4 W, 10% |
| Z1, Z2 | MICROSTRIPLINE – 0.275" W x 4.13" L |

Board – Glass Teflon, ε = 2.56, t = 0.062"
Input/Output Connectors – Type N

## TYPICAL PERFORMANCE DATA

FIGURE 2 – OUTPUT POWER versus FREQUENCY

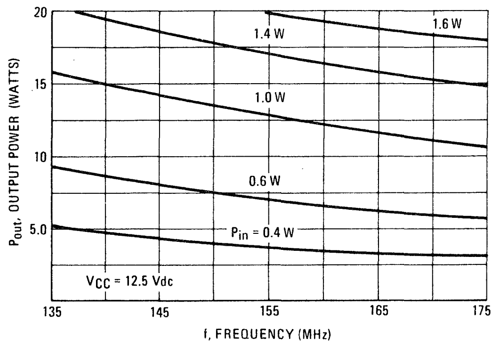



FIGURE 3 – OUTPUT POWER versus INPUT POWER

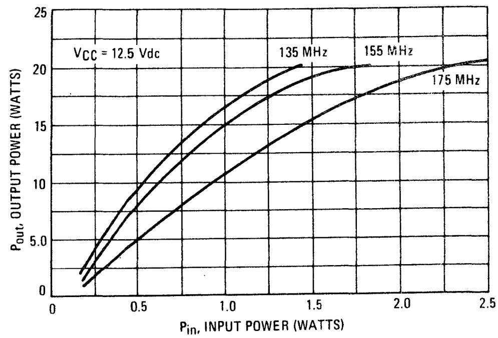



FIGURE 4 – TYPICAL GAIN versus FREQUENCY

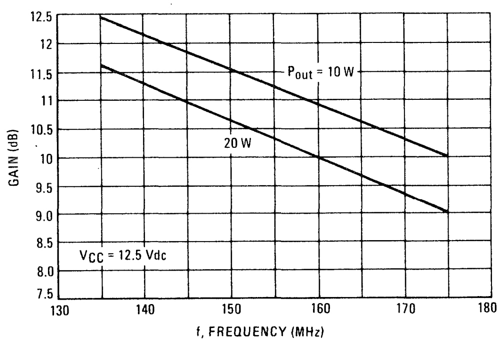
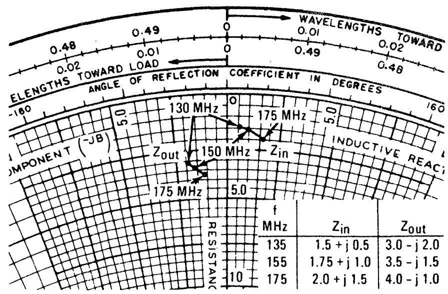
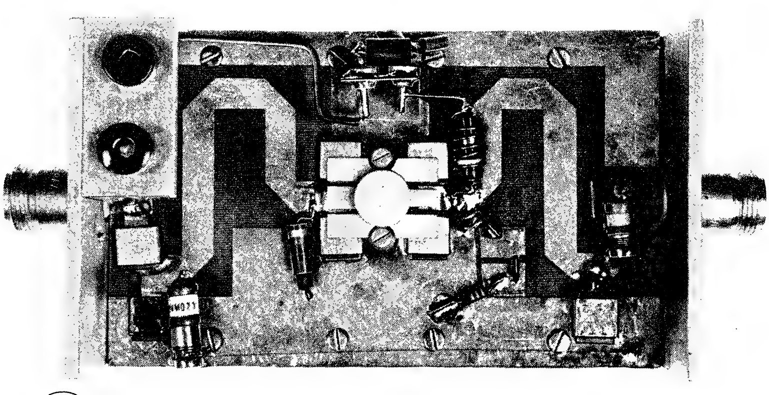



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE PARAMETERS




| f MHz | $Z_{in}$ | $Z_{out}$ |
|---|---|---|
| 135 | 1.5 + j 0.5 | 3.0 - j 2.0 |
| 155 | 1.75 + j 1.0 | 3.5 - j 1.5 |
| 175 | 2.0 + j 1.5 | 4.0 - j 1.0 |

FIGURE 6 – 175 MHz TEST CIRCUIT LAYOUT



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF216

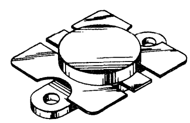
## The RF Line

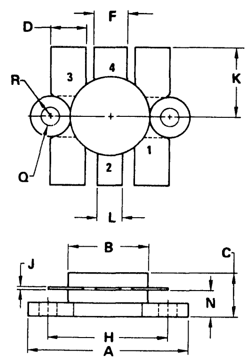
**40 W – 175 MHz CONTROLLED Q RF POWER TRANSISTOR NPN SILICON**

### NPN SILICON RF POWER TRANSISTOR

. . .designed for 12.5 Volt VHF large-signal amplifier applications in industrial and commercial FM equipment operating to 175 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics–
  Output Power = 40 Watts
  Minimum Gain = 6.7 dB
  Efficiency = 60%
- 100% Tested for Load Mismatch at all Phase Angles with 20:1 VSWR
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broad Band Operation






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

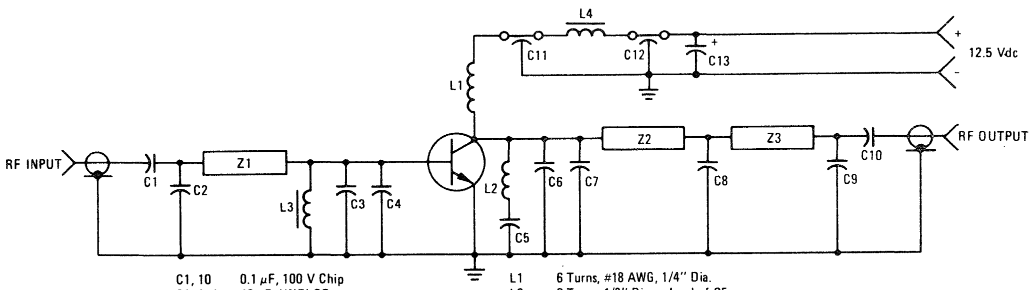
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 6.0 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 75<br>0.428 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as class B or C RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0 | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C = 55^oC$) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 2.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$=15 Vdc, $I_E$=0, f=1.0MHz) | $C_{ob}$ | – | 170 | 200 | pF |
| **FUNCTIONAL TEST** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 6.7 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 60 | – | – | % |
| Load Mismatch ($P_{out}$ = 40 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz, VSWR = 20:1, all phase angles) | – | No Degradation in Output Power | | | |

**FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC**




| | | | | |
|---|---|---|---|---|
| C1, 10 | 0.1 μF, 100 V Chip | | L1 | 6 Turns, #18 AWG, 1/4" Dia. |
| C2, 3, 4 | 40 pF, UNELCO | | L2 | 3 Turns, 1/8" Dia on Lead of C5 |
| C5 | 0.1 μF, 100 V Disc Ceramic | | L3, L4 | FERRITE Choke. FERROXCUBE VK200-10-4B |
| C6, 7 | 10 pF, UNELCO | | Z1 | MICROSTRIPLINE, 0.300" Wide, 3.20" Long |
| C8 | 25 pF, UNELCO | | Z2 | MICROSTRIPLINE, 0.300" Wide, 0.50" Long |
| C9 | 60 pF, UNELCO | | Z3 | MICROSTRIPLINE, 0.300" Wide, 1.90" Long |
| C11, 12 | 680 pF, ALLEN BRADLEY Feedthru | | Board – Glass Teflon, $\epsilon$ = 2.56, t = 0.062" | |
| C13 | 1.0 μF, 35 V, TANTALUM | | Input/Output Connectors – Type N | |

## TYPICAL PERFORMANCE DATA

FIGURE 2 — OUTPUT POWER versus FREQUENCY

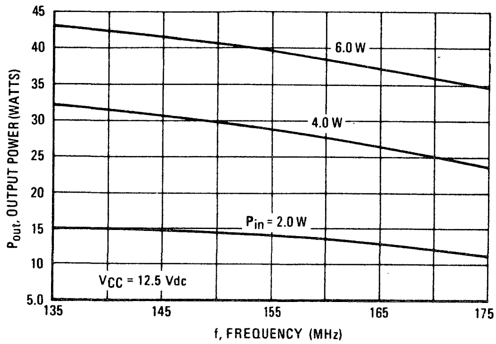



FIGURE 3 — OUTPUT POWER versus INPUT POWER

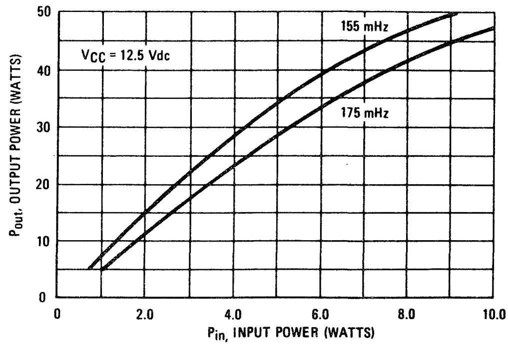



FIGURE 4 — TYPICAL GAIN versus FREQUENCY

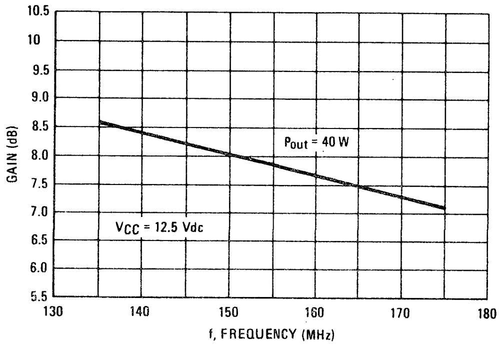
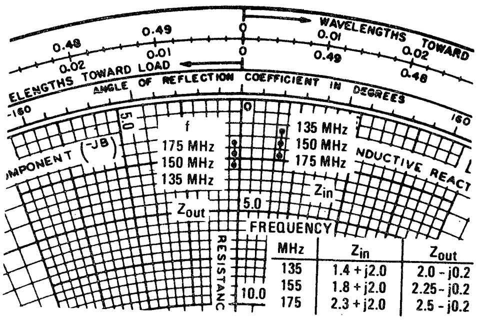
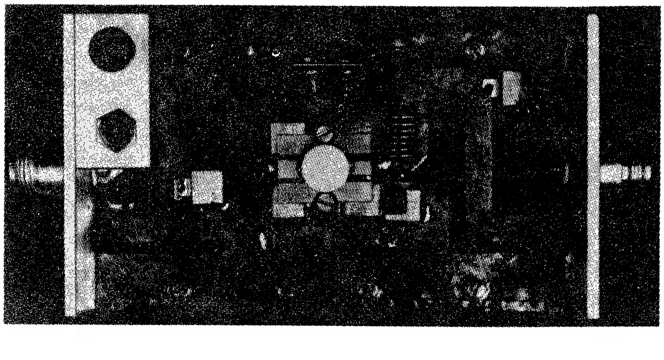



FIGURE 5 — SERIES EQUIVALENT IMPEDANCE PARAMETERS




| MHz | $Z_{in}$ | $Z_{out}$ |
|---|---|---|
| 135 | 1.4 + j2.0 | 2.0 - j0.2 |
| 155 | 1.8 + j2.0 | 2.25 - j0.2 |
| 175 | 2.3 + j2.0 | 2.5 - j0.2 |

FIGURE 6 — 175 MHz TEST CIRCUIT LAYOUT



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF237

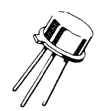
## The RF Line

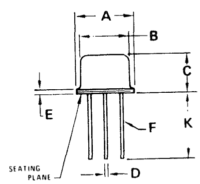
4 W – 175 MHz
RF POWER
TRANSISTOR
NPN SILICON

### NPN SILICON RF POWER TRANSISTOR

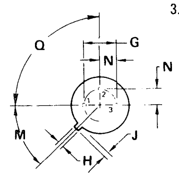
. . . designed for 12.5 Volt large-signal power amplifier applications in communication equipment operating to 225 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 4.0 Watts
  Minimum Gain = 12 dB
  Efficiency = 50%
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Grounded Emitter TO-39 Package for High Gain and Excellent Heat Dissipation
- Replaces Medium Power Stud Mount Devices






STYLE 5:
PIN 1. COLLECTOR
2. BASE
3. EMITTER




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |

CASE 79-03

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 640 | mAdc |
| Total Power Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 8.0<br>45.7 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

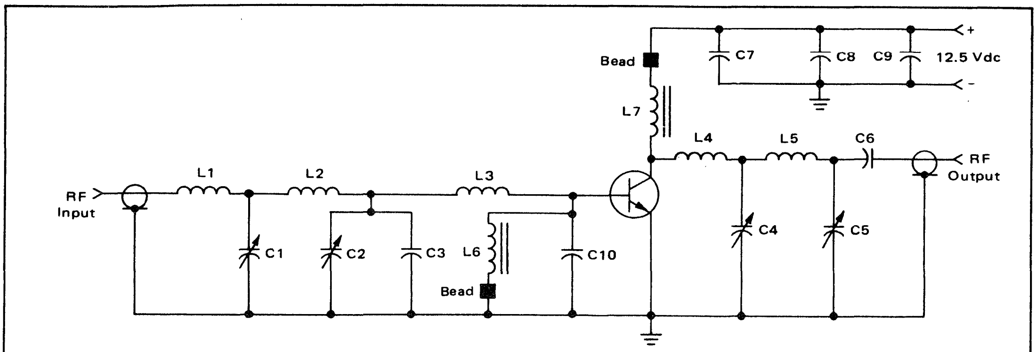
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 20 | $^oC/W$ |

### ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ =5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.25 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{ob}$ | – | 15 | 20 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 4.0 W, $V_{CC}$ = 12.5 Vdc, $I_C$ (max) = 640 mAdc, f = 175 MHz) | $G_{PE}$ | 12 | 14 | – | dB |
| Collector Efficiency ($P_{out}$ = 4.0 W, $V_{CC}$ = 12.5 Vdc, $I_C$ (max) = 640 mAdc, f = 175 MHz) | $\eta$ | 50 | 62 | – | % |

FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC




| | |
|---|---|
| C1,C4,C5 | 3.0 - 180 pF, ARCO 463 |
| C2 | 1.75 - 30 pF, ARCO 461 |
| C3 | 40 pF, UNELCO |
| C6 | 0.01 μF, ERIE |
| C7 | 0.1 μF, ERIE REDCAP |
| C8 | 1.0 μF, TANTALUM |
| C9 | 1000 pF, UNELCO |
| C10 | 100 pF UNELCO |

| | |
|---|---|
| L1 | 1/2 Turn, #16 AWG, 0.5" I.D. |
| L2 | 1", #16 AWG |
| L3 | 0.75" #16 AWG |
| L4,L5 | 1 Turn, #16 AWG, 0.5" I.D. |
| L6 | 0.15 μH Molded Choke |
| L7 | 1.2 μH Molded Choke |
| Beads | FERRITE Beads, FERROXCUBE #56-570-65/3B |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

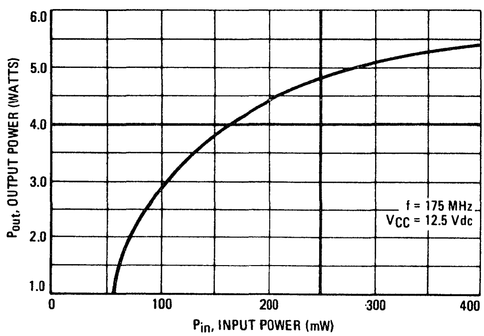



FIGURE 3 – OUTPUT POWER versus FREQUENCY

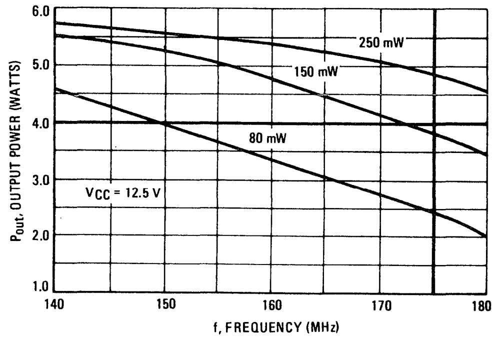



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

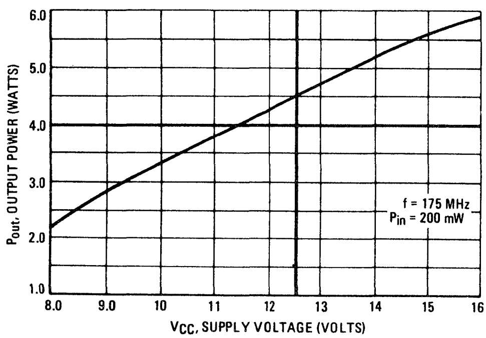
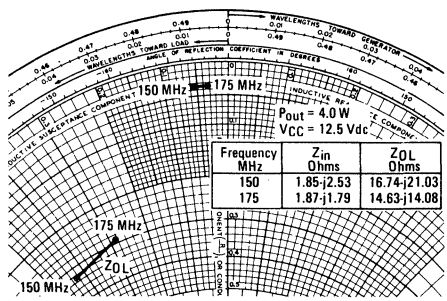



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF238

## Advance Information

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

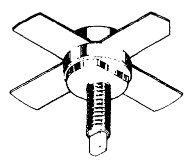
. . . designed for 13.6 Volt VHF large-signal amplifier applications in industrial and commercial FM equipment operating to 175 MHz. Ideally suited for marine radio applications.

- Specified 13.6 Volt, 160 MHz Characteristics –
  Output Power = 30 Watts
  Minimum Gain = 9.0 dB
  Efficiency = 60%

**30 W – 160 MHz**

**RF POWER TRANSISTOR**

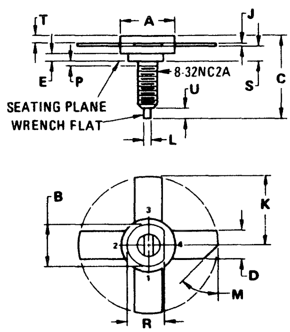
**NPN SILICON**



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 65<br>0.37 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |
| Stud Torque (1) | – | 6.5 | In. Lb. |

(1) For Repeated Assembly use 5 In. Lb.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | $45^o$ NOM | | $45^o$ NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

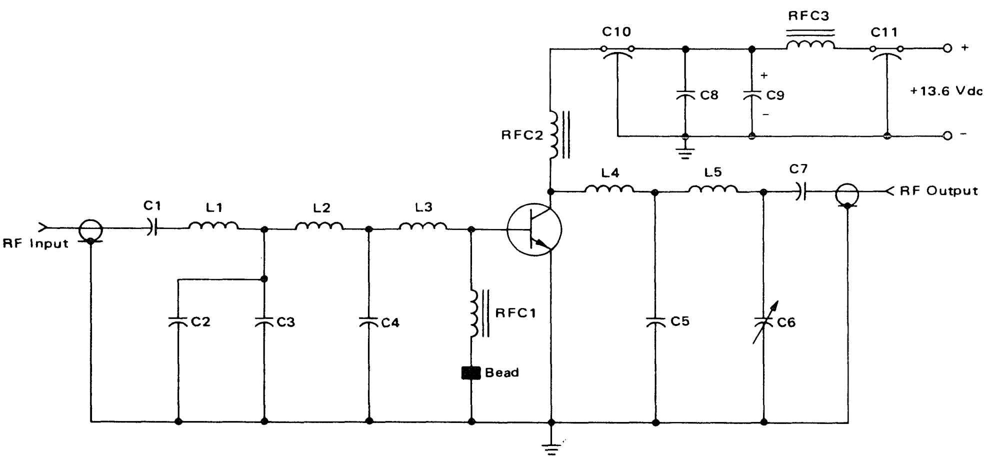
145A-09

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 15 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 110 | 130 | pF |
| **FUNCTIONAL TEST (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, $I_C$ (max) = 4.0 Adc, f = 160 MHz) | $G_{pe}$ | 9.0 | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 30 W, $I_C$ (max) = 4.0 Adc, f = 160 MHz) | $\eta$ | 60 | – | – | % |

**FIGURE 1 – 160 MHz TEST CIRCUIT SCHEMATIC**




C1 200 pF, 350 Vdc, UNELCO
C2 100 pF, 350 Vdc, UNELCO
C3 40 pF, 350 Vdc, UNELCO
C4,C5 80 pF, 350 Vdc, UNELCO
C6 1.0-20 pF, 4 oz. ARCO Trimmer
C7 100 pF 350 Vdc, UNELCO
C8 0.1 µF ERIE Disc Ceramic
C9 0.1 µF TANTALUM
C10,C11 680 pF ALLEN BRADLEY Feedthru
RFC1 0.15 µH Molded Choke
RFC2 10 Turns, #18 AWG on 470 Ohm, 1 Watt Resistor
Bead FERROXCUBE Bead
RFC3 FERROXCUBE Choke, VK200-4B

L1 3.3 x 0.2 cm AIRLINE Inductor
L2 1.0 x 0.2 cm AIRLINE Inductor
L3 1.2 x 0.6 cm Brass Pad
L4 1.2 x 0.6 cm Brass Pad and 2.0 x 0.2 cm AIRLINE Inductor

Board: G10, $\epsilon_r$ = 5, t = 62 mils, 2 sided, 2 oz. Clad

Connectors: Type N

FIGURE 2 — OUTPUT POWER versus INPUT POWER

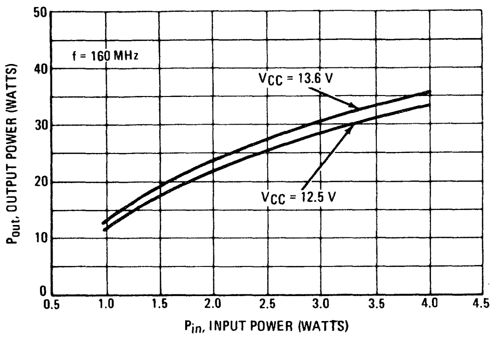



FIGURE 3 — OUTPUT POWER versus FREQUENCY

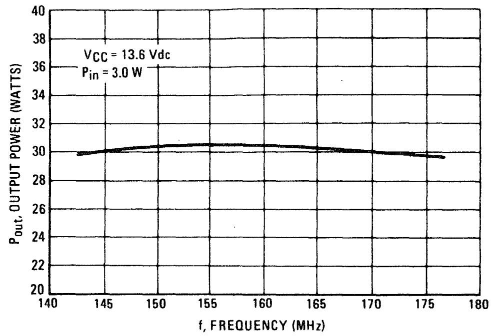



FIGURE 4 — OUTPUT POWER versus SUPPLY VOLTAGE

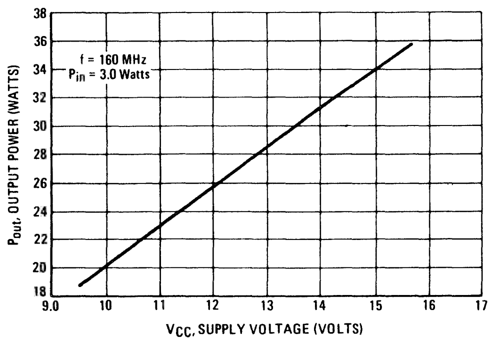
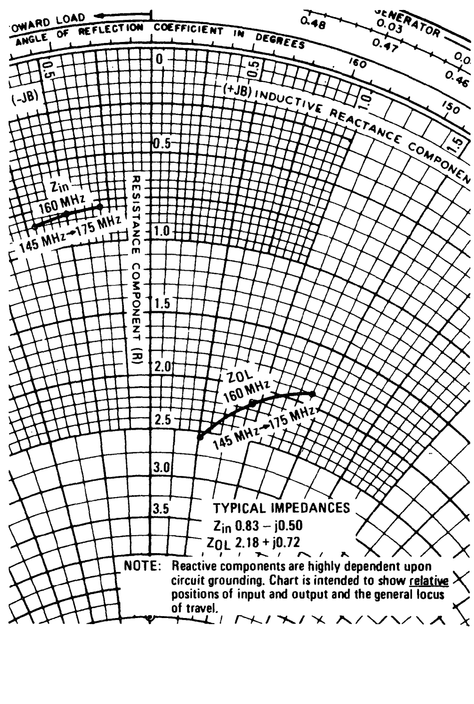



FIGURE 5 — SERIES EQUIVALENT IMPEDANCE



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036


# MRF243

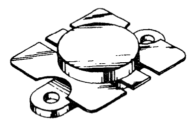
## Advance Information

## The RF Line

60 W – 175 MHz

**CONTROLLED Q RF POWER TRANSISTOR**

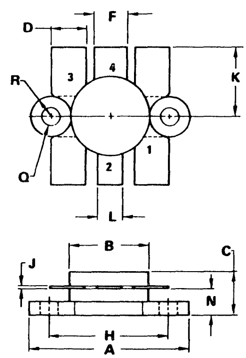
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt VHF large-signal amplifier applications in industrial and commercial FM equipment operating to 175 MHz.

- Specified 12.5 Volt, 175 MHz Characteristics –
  - Output Power = 60 Watts
  - Minimum Gain = 7.0 dB
  - Efficiency = 55%
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- Capable of Withstanding VSWR of 20:1 at Rated $P_{out}$ and Voltage




STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Peak | $I_C$ | 15 | Adc |
| Total Device Dissipation @ $T_C = 25^\circ C$<br>Derate Above $25^\circ C$ | $P_D$ | 175<br>1.0 | Watts<br>$W/^\circ C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^\circ C$ |

### THERMAL CHARACTERISTICS

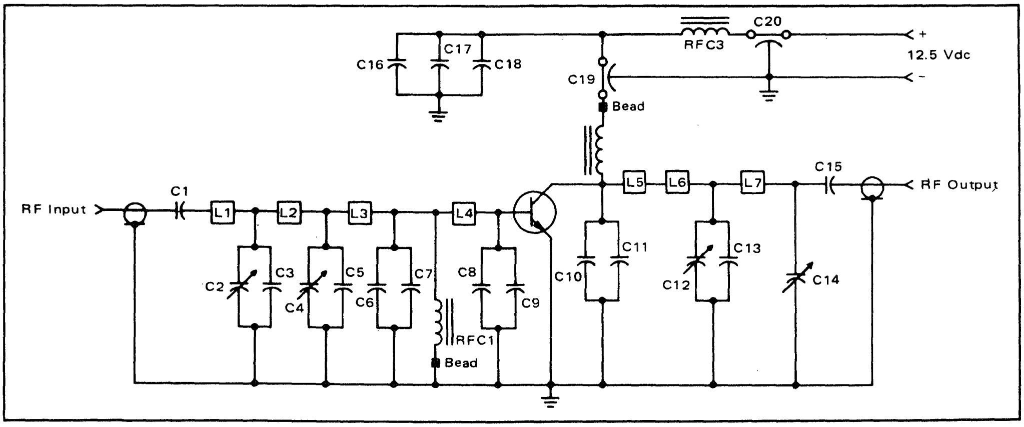
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.0 | $^\circ C/W$ |

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 35 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 250 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 Watts, f = 175 MHz) | $G_{PE}$ | 7.0 | – | – | dB |
| Input Power ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 Watts, f = 175 MHz) | $P_{in}$ | – | 10 | 12 | Watts |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 60 Watts, f = 175 MHz) | $\eta$ | 55 | 60 | – | % |

**FIGURE 1 — 175 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1, C15 | 500 pF Dipped Mica | RFC1 | 0.15 μH Molded Choke |
| C2, C4, C12, C14 | 2.0 – 15 pF EF JOHNSON Trimmer T9165 | RFC2 | 6 Turns, #18 AWG Enameled Wire, Wrapped on 560 Ω, 1 W Resistor |
| C3 | 25 pF UNELCO | | |
| C5 | 40 pF UNELCO | RFC3 | Ferrite Choke, FERROXCUBE VK200-10-4B |
| C6, C7 | 100 pF UNELCO | Bead | FERROXCUBE Bead 56-590-65-3B |
| C8, C13 | 60 pF UNELCO | L1 | 0.5" x 0.125" AIRSTRIP Inductors |
| C9 | 200 pF UNELCO | L2, L7 | 2.0" x 0.125" AIRSTRIP Inductor |
| C10 | 80 pF UNELCO | L3, L6 | 1.0" x 0.125" AIRSTRIP Inductor |
| C11 | 250 pF UNELCO | L4 | 1/16" Eyelet, 0.059" Outer Diameter |
| C16 | 0.1 μF, 50 Vdc ERIE REDCAP | L5 | 1/16" Eyelet, 0.059" Outer Diameter and 0.5" x 0.125" AIRSTRIP Inductor |
| C17 | 1.0 μF, 35 Vdc TANTALUM | | |
| C18 | 10 μF, 35 Vdc Electrolytic | Board: | G10, $\epsilon_r \approx 5$, t = 62 mils, 2 sided 2 oz. Copper Clad |
| C19, C20 | 680 pF ALLEN-BRADLEY Feedthrough | Connectors: | Type N, UG58 A/U |

This circuit is designed with passive components on bottom of board.
See Engineering Bulletin EB-46.

FIGURE 2 – OUTPUT POWER versus INPUT POWER

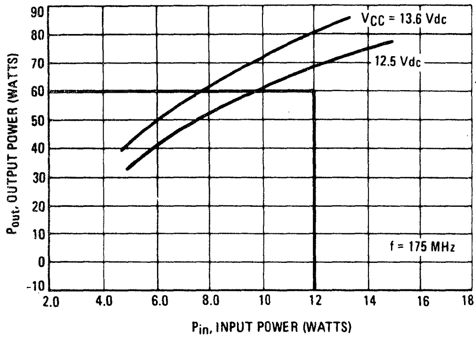



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

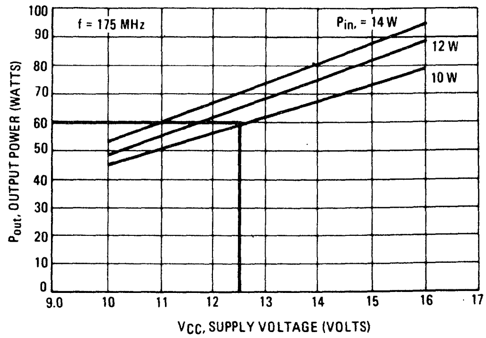



FIGURE 4 – OUTPUT POWER versus FREQUENCY

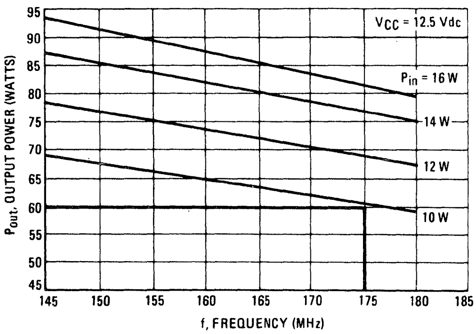
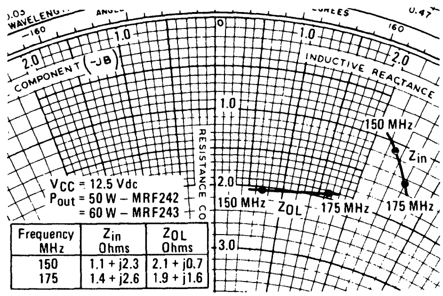



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 150 | 1.1 + j2.3 | 2.1 + j0.7 |
| 175 | 1.4 + j2.6 | 1.9 + j1.6 |

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**Semiconductors**
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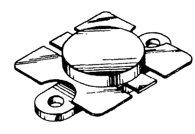
# MRF245

## The RF Line

80 W – 175 MHz

**CONTROLLED Q**
**RF POWER**
**TRANSISTOR**

**NPN SILICON**



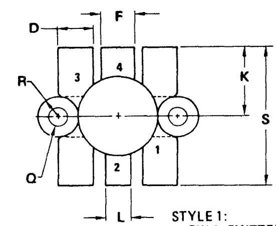
### NPN SILICON RF POWER TRANSISTORS

. . . designed for 12.5 Volt VHF large-signal amplifier applications in industrial and commercial FM equipment operating to 175 MHz.

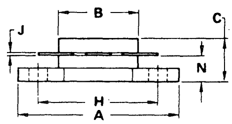
- Specified 12.5 Volt, 175 MHz Characteristics –

  Output Power = 80 Watts
  Minimum Gain = 6.4 dB
  Efficiency = 55%
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- Capable of Withstanding VSWR of 20:1 at Rated $P_{out}$ and Voltage

NOTE: Operation in excess of 100 Watts not recommended.
For recommended operation and circuits see Engineering Bulletin EB-46.




STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Peak | $I_C$ | 20 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 250<br>1.43 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | $^oC$ |

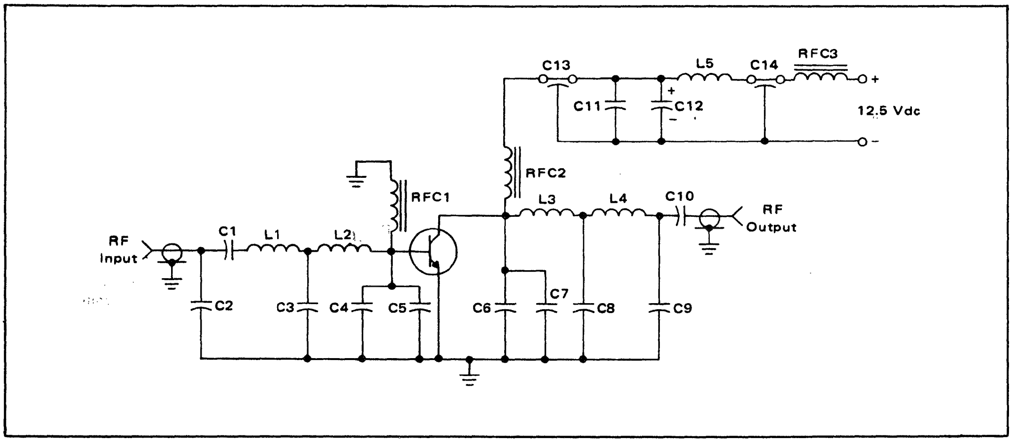
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.7 | $^oC/W$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 100 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | 35 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 250 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 Watts, f = 175 MHz) | $G_{PE}$ | 6.4 | – | – | dB |
| Input Power ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 Watts, f = 175 MHz) | $P_{in}$ | – | 12 | 18 | Watts |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 80 Watts, f = 175 MHz) | $\eta$ | 55 | 60 | – | % |

**FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1, 4, 5, 6, 7 | 250 pF UNELCO | L1 | 5.0 x 0.2 cm Airline Inductor |
| C2 | 25 pF UNELCO | L2 | 2.0 x 0.2 cm Airline Inductor |
| C3, 8 | 80 pF UNELCO | L3 | 2.4 x 0.2 cm Airline Inductor |
| C9 | 10 pF UNELCO | L4 | 4.5 x 0.2 cm Airline Inductor |
| C10 | 1000 pF UNELCO | L5 | 2.0 cm AWG #16 Wire |
| C11 | 0.1 μF Erie Disc Ceramic | Board: | G10, $\epsilon_r \approx 5$, t = 62 mils |
| C12 | 1.0 μF Tantalum | Connectors: | Type N |
| C13, 14 | 680 pF Allen Bradley Feedthru | | |
| RFC1 | VK200-4B Ferroxcube Choke | | |
| RFC2 | 10 Turns #18 AWG Enameled Wire on 470 Ω 2 W Resistor | | |
| RFC3 | Fairite #2643021801, Ferrite Bead | | |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

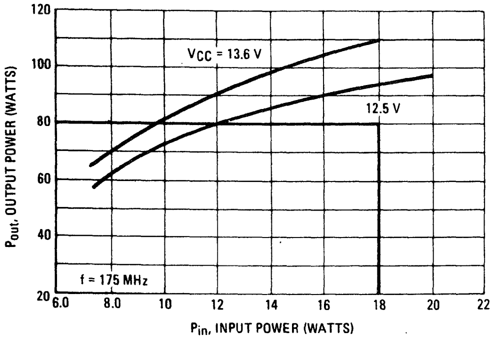



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE

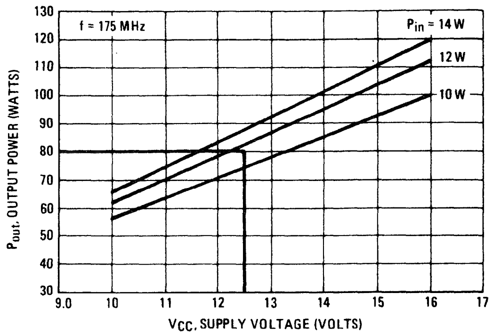



FIGURE 4 – OUTPUT POWER versus FREQUENCY

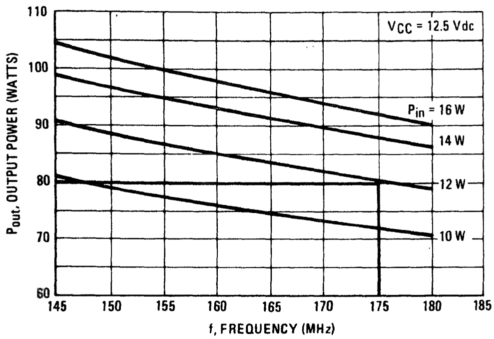
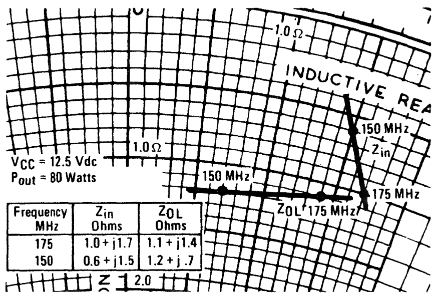



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE



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Semiconductors
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# MRF604

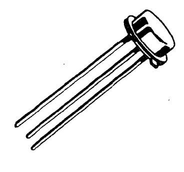
## The RF Line

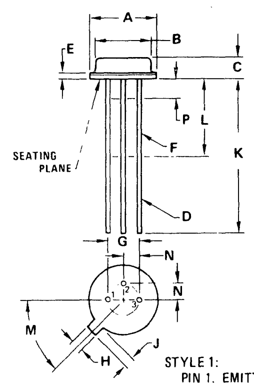
1.0 W – 175 MHz
RF POWER
TRANSISTOR
NPN SILICON

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt VHF large-signal amplifier applications in industrial equipment with restricted available space.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 10 dB
  Efficiency = 50%






STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 1.65 | 2.16 | 0.065 | 0.085 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | – | 1.02 | – | 0.040 |
| F | 0.305 | 0.483 | 0.012 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.914 | 1.17 | 0.036 | 0.046 |
| J | 0.711 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

All JEDEC dimensions and notes apply

CASE 26-03
TO-46

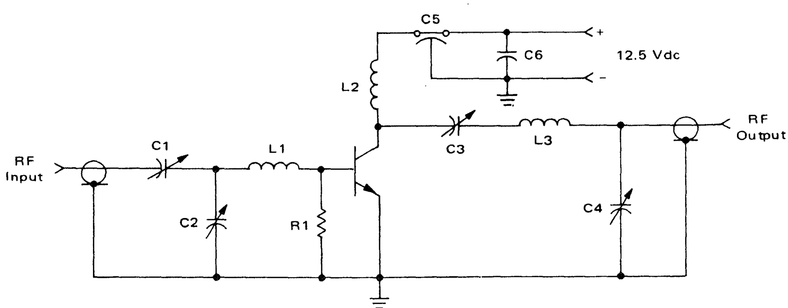
### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 2.0 | Vdc |
| Total Device Dissipation @ $T_C = 25^\circ C$<br>Derate above $25^\circ C$ | $P_D$ | 2.5<br>0.04 | Watts<br>$W/^\circ C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^\circ C$ |

ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 12 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 80 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 10 Vdc, f = 200 MHz) | $f_T$ | 800 | – | – | MHz |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 3.5 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, f = 175 MHz) | $G_{PE}$ | 10 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, f = 175 MHz) | $\eta$ | 50 | – | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, f = 175 MHz) | $Z_{in}$ | – | 7.5-j 14 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, f = 175 MHz) | $Z_{out}$ | – | 47-j 60 | – | Ohms |

FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC




| | |
|---|---|
| C1,C2,C3,C4 | 3.0-30 pF |
| C5 | 1000 pF |
| C6 | 0.01 μF |
| L1 | 2 Turns, #16 AWG, 3/16" I.D., 1/4" Long |
| L2 | 0.15 μH, MOLDED CHOKE |
| L3 | 4 Turns, #16 AWG, 3/8" I.D., 3/8" Long |
| R1 | 100 Ω, 1/4 W, 10% |

FIGURE 2 — OUTPUT POWER versus INPUT POWER

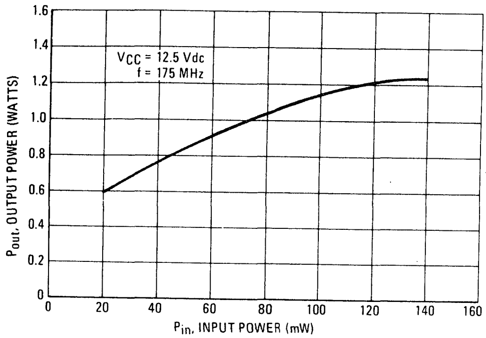



FIGURE 3 — CURRENT-GAIN BANDWIDTH PRODUCT

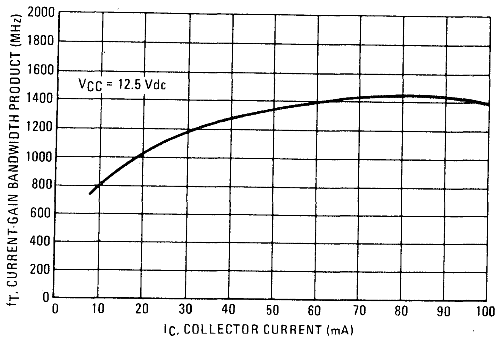
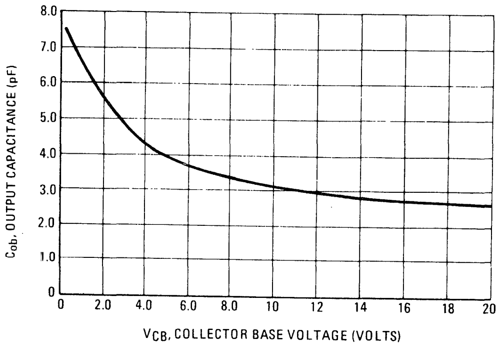



FIGURE 4 — OUTPUT CAPACITANCE versus COLLECTOR BASE VOLTAGE



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF607

## The RF Line

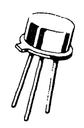
### NPN SILICON RF POWER TRANSISTOR

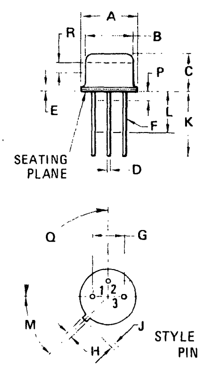
. . . designed for amplifier, frequency multiplier, or oscillator applications in military, mobile, marine and citizens band equipment. Suitable for use as output driver or pre-driver stages in VHF and UHF equipment.

- Specified 12.5 Volt, 175 MHz Characteristics –
  Output Power = 1.75 Watts
  Minimum Gain = 11.5 dB
  Efficiency = 50%
- Characterized through 225 MHz

**1.75 W – 175 MHz**

**RF POWER TRANSISTOR NPN SILICON**






STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

**CASE 79-02**
**TO-39**

All JEDEC notes and dimensions apply.

### MAXIMUM RATINGS

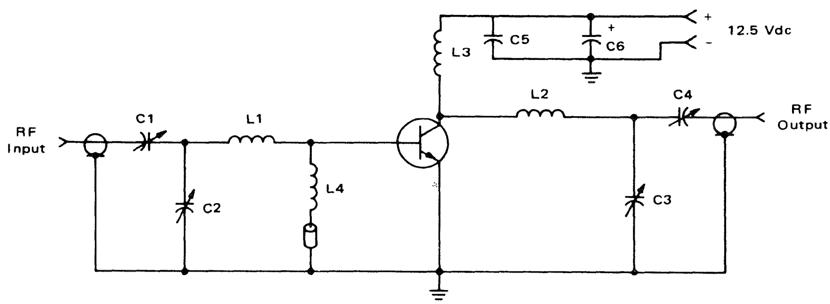
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.33 | Adc |
| Total Device Dissipation @ $T_C$ = 75°C (1)<br>Derate above 75°C | $P_D$ | 3.5<br>28 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as class B or C RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 25 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 10 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | 0.3 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 50 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 15 | pF |
| **FUNCTIONAL TEST** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 1.75 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $G_{PE}$ | 11.5 | – | dB |
| Collector Efficiency ($P_{out}$ = 1.75 W, $V_{CC}$ = 12.5 Vdc, f = 175 MHz) | $\eta$ | 50 | – | % |

FIGURE 1 – 175 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1 | 2.7-15 pF, ARCO 461 | L1 | 1 Turn #20 AWG, 3/8" ID |
| C2 | 9.0-180 pF, ARCO 463 | L2 | 3 Turns #20 AWG, 3/8" ID |
| C3,C4 | 5.0-80 pF, ARCO 462 | L3 | 0.22 µH Molded Choke |
| C5 | 1000 pF UNELCO | L4 | 0.15 µH Molded Choke with FERROXCUBE 56-590-65-3B Bead on ground lead |
| C6 | 5 µF, 25 Vdc, TANTALUM | | |

## TYPICAL PERFORMANCE DATA

FIGURE 2 – OUTPUT POWER versus FREQUENCY

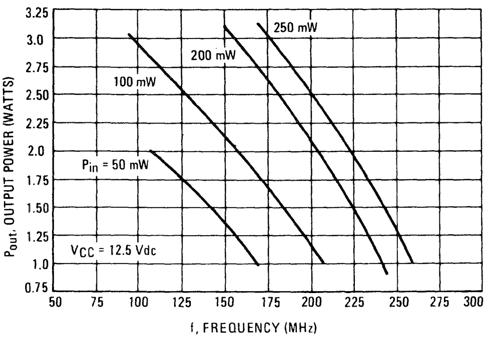



FIGURE 3 – OUTPUT POWER versus INPUT POWER

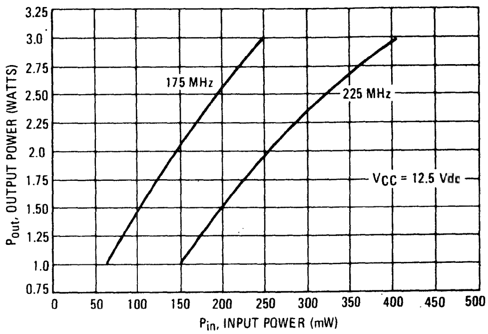



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

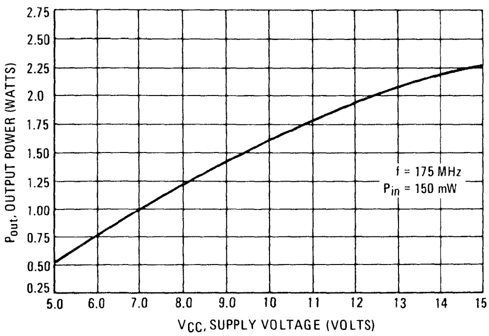
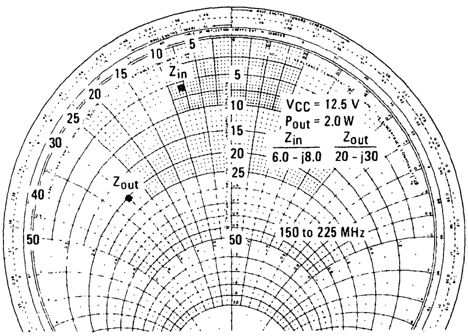



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE PARAMETERS



# Simple VHF Broadband Design Uses CQ Transistor Lineup

The full use of the VHF band has produced a spectacular increase in new designs and equipment, an increase spurred even more by improvements in RF transistors and concurrent expansion of the lines offered by major producers. Motorola is keeping the ball rolling by developing new designs using its state-of-the-art devices to show how you can improve existing systems or design new ones.

Here are the details of a compact, fixed-tuned amplifier for the 132- to 175-MHz band that uses our latest Controlled-Q transistor. The amplifier combines high-gain efficiency, circuit simplicity, good bandwidth, and the ability to withstand high VSWRs.

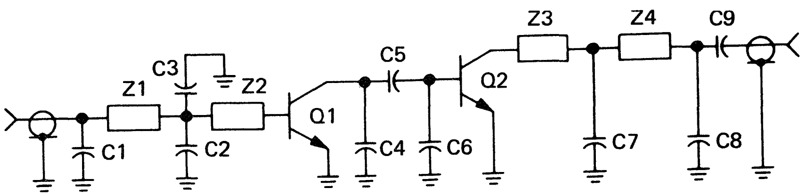
Tests of our ampifier reveal that an input of approximately 1.0 W is needed for a 40-W output at 12.5 V. Efficiency is approximately 70% at 175 MHz and gradually decreases to about 50% at 132 MHz. The second harmonic is greater than 40 dB down at 132 MHz and more than 55 dB down at 175 MHz. Non-harmonically related signals are a minimum of 60 dB down. The amplifier has successfully operated at 30:1 VSWR at all phase angles.

## Controlled-Q Transistors Line Up For 40 Watts

Two flange mount devices are used in the amplifier: MRF216, a 40-W internally matched device using the proven die for the 2N6084, and the MRF221, a flange version of the 2N6081. The circuit combines Chebychev low-pass impedance transforming networks on the input and output with a special interstage network that matches device impedance parameters.

Figure 1 shows a partial schematic of the amplifier circuit with important RF components indicated. In this type of circuit, it can be considered roughly that the first L-C network near each transistor sets the upper band edge, while the second L-C network optimizes the total band performance.

FIGURE I




Q1 – MRF221 transistor
Q2 – MRF216 transistor

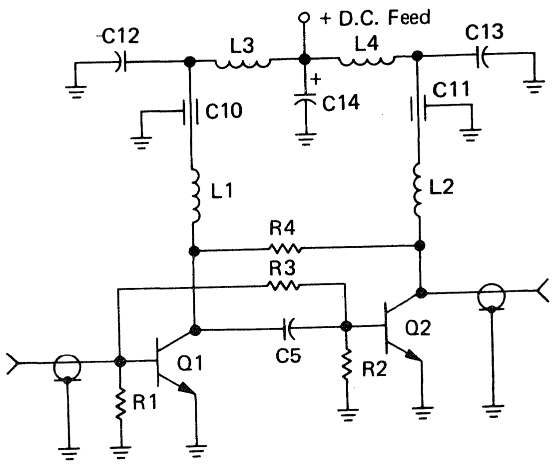
| | WIDTH | LENGTH |
|---|---|---|
| Z1 – | 0.100 in. | 2.400 in. |
| Z2 – | 0.100 in. | 0.350 in. |
| Z3 – | 0.100 in. | 0.400 in. |
| Z4 – | 0.100 in. | 2.800 in. |

C1, 3, 8 – 40 pF UNELCO capacitor
C2, 7 – 200 pF UNELCO capacitor
C4, 6 – 60 pF UNELCO capacitor
C5 – >1000 pF ceramic chip capacitor
C9 – Two 0.018 μF Vitramon chip capacitors in parallel
Board – 0.062, 2 oz., 2-sided Cu-clad, type G-10

## Computer Aids Design

Actual circuit values were derived by using the Motorola computer-aided design program "NETWK." The interstage matching network was empirically designed to achieve the best compromise between efficiency, saturated power, and gain.

FIGURE II

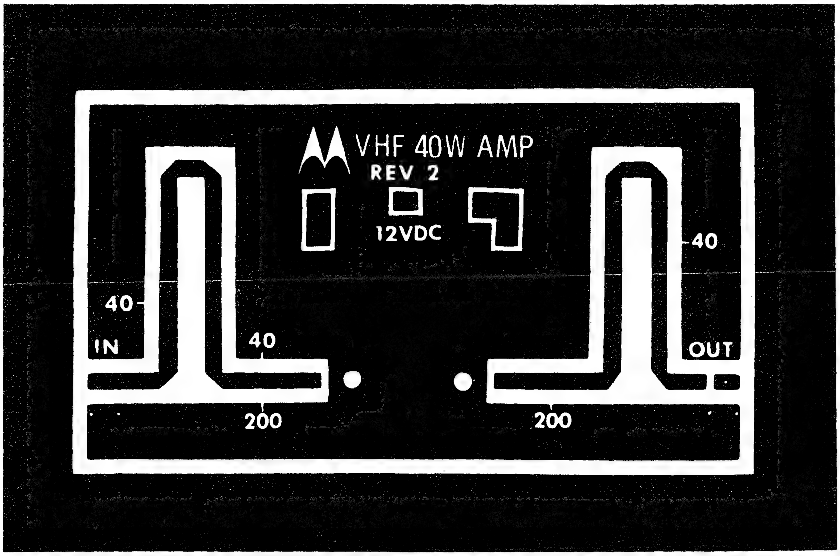



R1, 2 – 1 ohm, 1 W carbon resistor
R3, 4 – 22 ohm, 1/2 W carbon resistor
L1, 2 – .15 μH molded choke
L3, 4 – Ferroxcube VK200 inductor; three Ferroxcube beads (56-590-65/4B) over #18 wire

C10, 11 – Allan Bradley 680 pF feedthru
C12, 13 – 1 μF, 35 V tantalum capacitor
C14 – 10 μF, 35 V tantalum capacitor
C5 – >1000 pF ceramic chip capacitor
Q1 – MRF221 transistor
Q2 – MRF216 transistor

Figure 2 shows the base and collector bias and bypass circuitry including the feedback network. Two 22-ohm resistors (R3, R4) are required to prevent instability at low input and/or voltage conditions. Because of the physical proximity of the two transistors, the two feedback resistors are placed base-to-base and collector-to-collector. This is equivalent to placing each resistor across the collector-to-base junction of each device and eliminates a coupling capacitor.

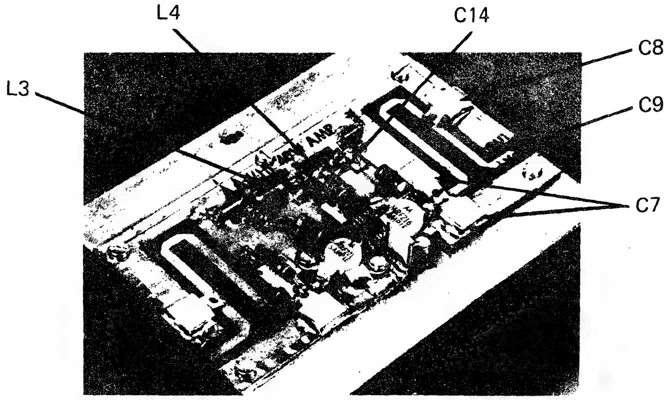
The two 60-pF UNELCO Capacitors (C4, C6) in the interstage network were placed on edge to facilitate the close physical spacing of the devices necessary for best operation over the entire band. To get optimum performance (nearly flat from 120- to 180-MHz), the amplifier was built displaying the output of a VHF-swept frequency test setup.




PC BOARD LAYOUT

## Put It All Together Like This

1. Use thermal compound beneath the transistors to ensure good heat transfer.
2. The interstage section can be assembled as in the photograph of the demonstration amplifier.
3. The input network is centered at about 170 MHz. Consequently, input VSWR is below 1.3:1 from 150 to 180 MHz and gradually rises to approximately 1.6:1 at 130 MHz. As mentioned earlier, the first L-C section (Z2, C2, C3) sets the top frequency cutoff while the next L-C section (Z1, C1) sets the bandwidth. The UNELCO capacitors used are ±20%, so slight changes in performance can be expected.




4. The output network is set so the amplifier just begins rolling off at 180 MHz. At 190 MHz, the output is down 6 dB and by 260 MHz, the output is down 40 dB. The first L-C section (Z3, C7) adjusts the upper roll-off and may be changed to effect a lower frequency cut-off by lengthening the first section of line from device to capacitor by a small amount. The second L-C section (Z4, C8) will affect the amplifier efficiency, and a careful watch of both efficiency and output power must be made while adjusting the L-C combination.
5. Continuous grounds on the board are essential to good, predictable operation of a broadband circuit. If wrapping or plating around the edges of the circuit board is not feasible, at least six fasteners per side should be used for ground transfer.
6. Transistors are located just as shown in the photograph. The mounting hole for the MRF216 should be cut so that the collector lies on the microstrip as close to the transistor package as possible. The emitter leads should be grounded to the PC board as close as possible. The same applies to the emitter leads on the MRF 221.
7. The board should be wrapped along the edges on all four sides for grounding purposes. Eyelets should be put through the board beneath each of the emitter leads of both parts.
8. A negative can be made by photographing the PC board layout, as it is full-scale reproduction of the board.

## For Best Results-Sweep

In conjunction with these hints, use of the positioning marks on the circuit board will produce reasonable performance from the amplifier while a swept test setup will get the maximum performance from each pair of transistors.

| Freq MHz | $P_{in}$ W | $P_{out}$ W | $I_c$ A | $V_{cc}$ V | Input VSWR |
|---|---|---|---|---|---|
| 180 | 1.25 | 40 | 5.5 | 12.5 | 1.3:1 |
| 170 | 1.00 | 40 | 5.3 | 12.5 | 1.15:1 |
| 160 | 0.90 | 40 | 5.7 | 12.5 | 1.15:1 |
| 150 | 1.00 | 40 | 6.5 | 12.5 | 1.3:1 |
| 140 | 1.35 | 40 | 7.5 | 12.5 | 1.45:1 |
| 130 | 1.70 | 40 | 8.5 | 12.5 | 1.6:1 |

# A Single-Device, 80-Watt, 50-Ohm VHF Amplifier

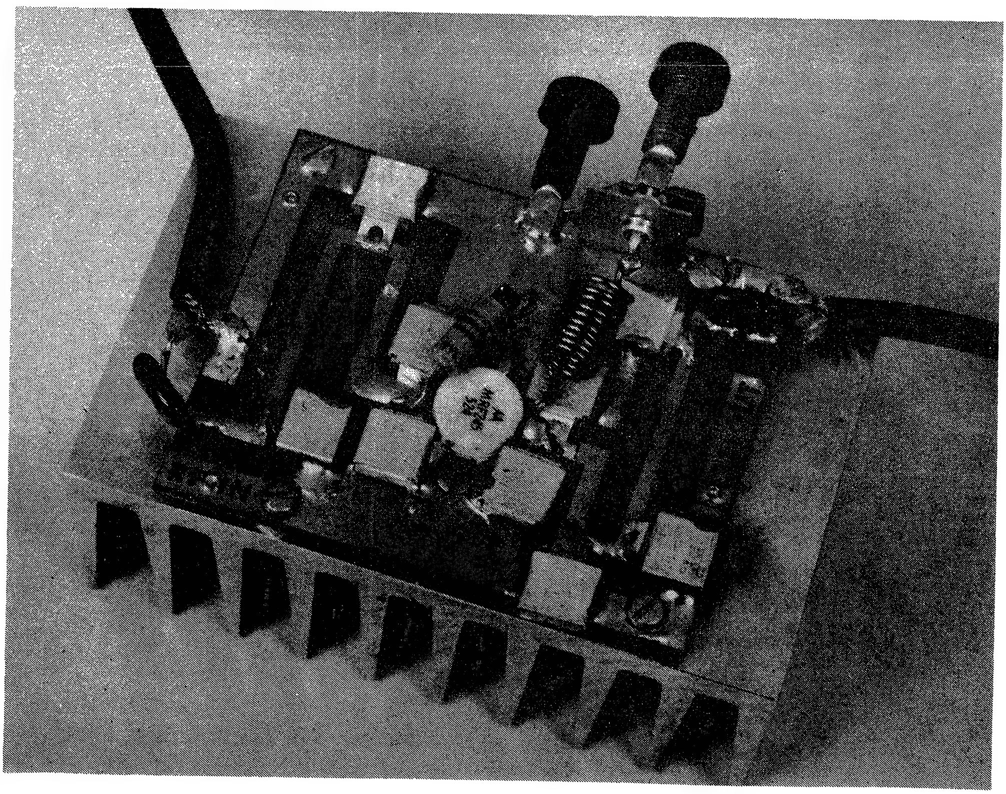
Revision in preparation. Request EB-46 from Motorola Semiconductor Products Inc., Literature Distribution Center, P.O. Box 20924, Phoenix, AZ 85036.

*Prepared by:*
**Tom Bishop**

The introduction of MRF245, an internally matched CQ* transistor for 12.5-volt operation, now makes possible single-device, 80-watt amplifiers operating at VHF bands at or below 175 MHz. This engineering bulletin describes the design and construction of an amplifier using a single MRF245 and providing 80 W with 9.4-dB gain across the 143- to 156-MHz band. Modifications of the basic amplifier for operation across broader bands are also discussed.

**The RF Transistor–MRF245**

The MRF245 is rated at 80 watts power output, 175 MHz, at 12.5 Vdc with a minimum of 6.4-dB gain. It features an L-type input matching in a CQ package for optimum broadband characteristics. This rugged device will withstand a 20:1 VSWR at all phase angles at rated operating conditions.



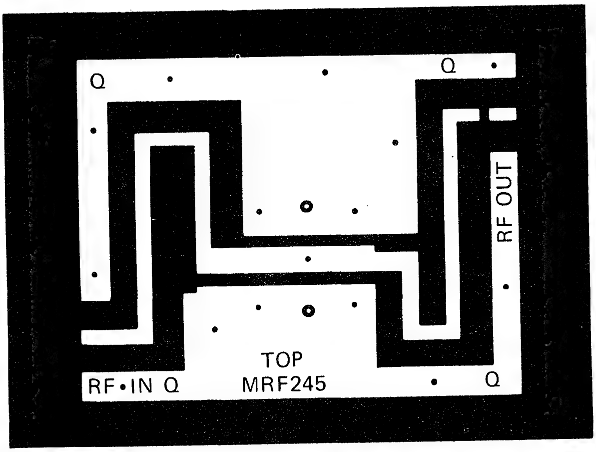
**The Building Block Amplifier**

The amplifier operates across the 143- to 156-MHz band with approximately 9.4 dB of gain. Eight watts of drive at 13.5 Vdc produces 80 watts of output power. With minor matching changes, the amplifier will operate across the 155- to 175-MHz band with typically 9.0-dB gain. Efficiency averages 60% across the bands, varying slightly with each variation used. The second harmonic at 150 MHz is -40 dB (40 dB below 80 W) without an output filter. Each version has been built and tested at a 20:1 VSWR mismatch at all phase angles with no degradation.

**Building the Board**

The basic amplifier is built on 57-gram, copper-clad, double-sided, printed circuit board measuring 6 x 7.7 cm. The material is G10, $\epsilon_r \approx 5$, t = 0.16 cm. Figure 1 is a 1:1 photomask for the top and bottom of the amplifier. Dots on the mask signify positions where eyelets are used to effectively interconnect the grounds on the top and bottom of the board. These are USM Electronic Eyelets "S-6084" or equivalent.

The series tuning inductors are printed strip lines with the ground plane removed beneath them. This technique reduces the $I^2R$ losses and improves the consistency of these critical elements. The elements are referred to as airlines or airstrip inductors later in the text. The letter "Q" signifies the placements of 4-40 screws used to fasten the board to the heatsink.



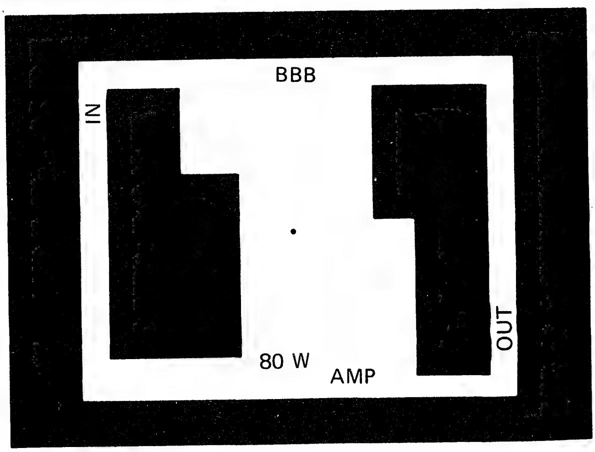
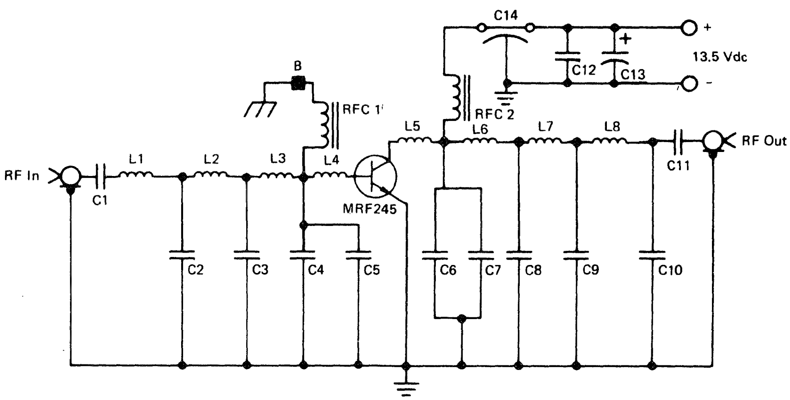




FIGURE 1. Photomask for Top and Bottom of PCB (Positive)




C1, 11 – 500 pF Dipped mica
C2, 9 – 10 pF UNELCO
C3 – 60 pF UNELCO
C4, 5 – 250 pF UNELCO
C6, 7 – 250 pF UNELCO
C8 – 80 pF UNELCO
C10 – 40 pF UNELCO
C12 – 0.1 $\mu$F Erie Redcap
C13 – 1 $\mu$F Tantalum
C14 – 680 pF Allen Bradley Feed-Thru

RFC 1 – 0.15 $\mu$H Molded choke
RFC 2 – 10 T NO. 18 AWG Enameled Wire, 1/4" I.D.
B – Ferroxcube Bead 56-590-65, 3 Beads

L1 – 1.2 X 0.3 cm Airline Inductor
L2 – 3.5 X 0.3 cm Airline Inductor
L3 – 4.0 X 0.3 cm Airline Inductor
L4, L5 – 0.3 X 0.3 cm Airline Inductor
L6 – 2.7 X 0.3 cm Airline Inductor
L7 – 0.8 X 0.3 cm Airline Inductor
L8 – 3.0 X 0.3 cm Airline Inductor

Board: G10, $\epsilon_r \approx 5$, t = 0.16 cm, 57 gm, Copper-Clad connectors = BNC

FIGURE 2. Circuit Schematic of 80-Watt, 143–156-MHz Power Amplifier

## Building the Amplifier

Figure 2 is the schematic diagram, with parts list, for the 143- to 156-MHz amplifier version. The base matching network consists of a three-section "L" network that transforms 50 ohms to the optimum broadband and load-line for the MRF245 at 80 watts.

Placement of the fixed capacitors is not extremely critical, but it is suggested that the top view photograph be used with the given "airline" measurements from Figure 2 to optimize performance. UNELCO capacitors or their equivalent are important due to the very high currents encountered in these components at 80 watts. In experiments, the "dipped mica" variety of capacitors were found to change values and sometimes overheat after prolonged use.

## Assembling the Amplifier on a Heatsink

Since airstrip inductors are used, it is important to keep the PC board clear of the heatsink to minimize RF losses and maintain inductor value. Insert a nut or spacer, 0.2-cm thick, between the board and the heatsink and put the 4-40 screws through the nuts. Figure 3 illustrates this idea. Be sure to put a thin film of thermal compound, Dow-Corning 340, on the heatsink of the transistor to obtain good heat transfer. The heatsink should be flat, with curvature under the part limited to +0.025, -0.000 cm, for best results.

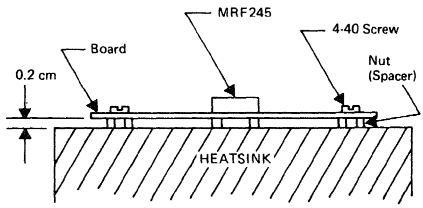



FIGURE 3. Sideview of Amplifier

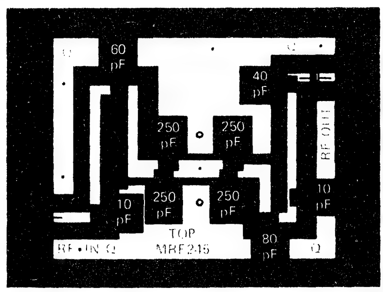



FIGURE 4. Capacitor Placement for 143–156-MHz Power Amplifier

## Frequency Band Options

Simple modifications can be made to the board layout to change the bandwidth performance of this amplifier. Recommended component value changes and placements are provided in Figures 5 and 6. Figure 5 shows the placement and values for the 155- and 175-MHz amplifier, Figure 6 the changes for the 143- to 170-MHz amplifier. Both amplifiers are capable of 80 watts output at 12.5 Vdc and are able to withstand a 20:1 VSWR.

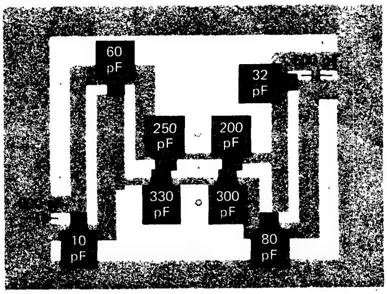



FIGURE 5. Parts Placement for 155–175-MHz Power Amplifier

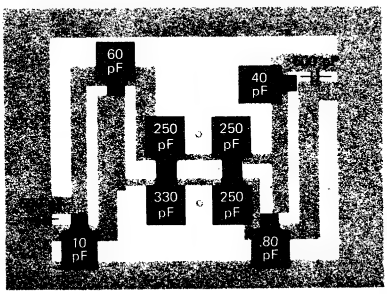



FIGURE 6. Parts Placement for 143–170-MHz Power Amplifier

The measured performance of the 143- to 156-MHz amplifier version is shown in Figure 7.

FIGURE 7. Performance Data for 143–156-MHz Amplifier at 13.5 Vdc

| Frequency MHz | $P_{in}$ W | $P_{out}$ W | $I_C$ A | Input VSWR |
|---|---|---|---|---|
| 143 | 10.0 | 80 | 12.0 | 2.1:1 |
| 146 | 9.0 | 80 | 11.5 | 1.8:1 |
| 148 | 8.5 | 80 | 11.0 | 1.6:1 |
| 150 | 8.3 | 80 | 11.0 | 1.5:1 |
| 152 | 8.3 | 80 | 10.5 | 1.6:1 |
| 154 | 8.5 | 80 | 10.0 | 1.8:1 |
| 156 | 9.0 | 80 | 10.0 | 1.8:1 |

## Operating Conditions

The three building block amplifiers, using the MRF245, show gains as high as 3 dB above the data sheet minimums and generally do not saturate until above 100 watts of output power. We recommend, therefore, that the builder monitor his drive power and limit output to 80 watts or less. Beyond this power, the ability of conventional circuit components to withstand very high VSWR mismatches is significantly reduced.

For more information on Transistor Mounting, see AN-555.

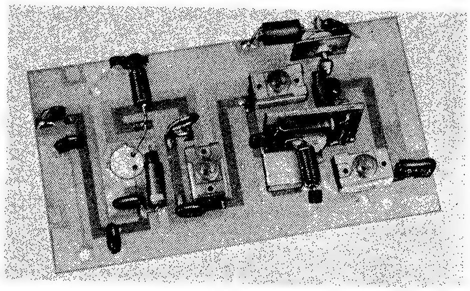
For more information on CQ technology, see EB-19.

# TwoVHF Highband Gain Blocks Form 20-dB, 30-Watt Amplifier Chain

*Prepared by:*
**Howard Burger and Tom Bishop**

The allocation by the FCC of the VHF Marine band immediately created a need for a communications radio of the consumer type that could be adapted to amateur and low-cost commercial usage. Meeting the cost and performance goals of such a radio will be challenging. It must be inexpensive, small, easily built from basic components and foolproof to tune in the field. Its power amplifier must provide outputs for both 25- and 1-watt levels and be stable under mismatch. Pre-filter harmonic levels should be very low.

The amplifier chain described in this bulletin will aid in meeting these goals. Built from two low-cost building blocks designed for use in VHF Marine/Amateur/Commercial equipment, it provides 20 dB of gain over any 10-MHz portion of that band or tunes larger band portions with slightly less gain.



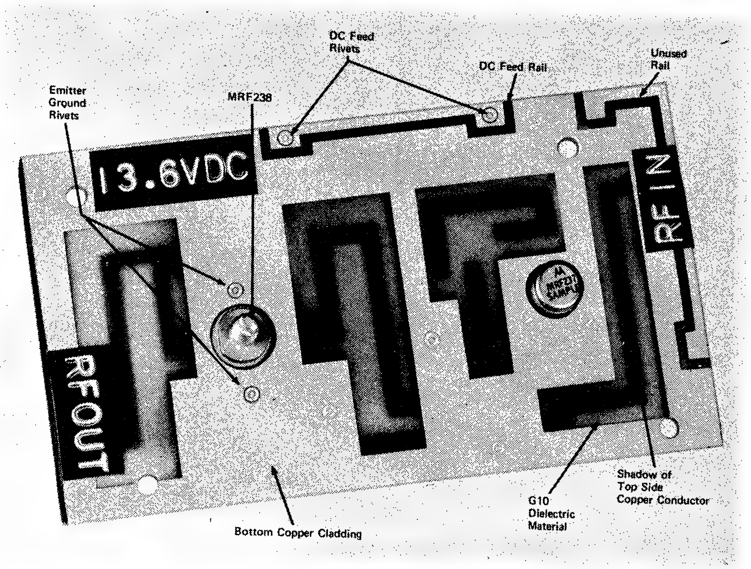



FIGURE 1.
Bottom View of PC Board with Backlighting Shows Relation of Airline to Ground Planes

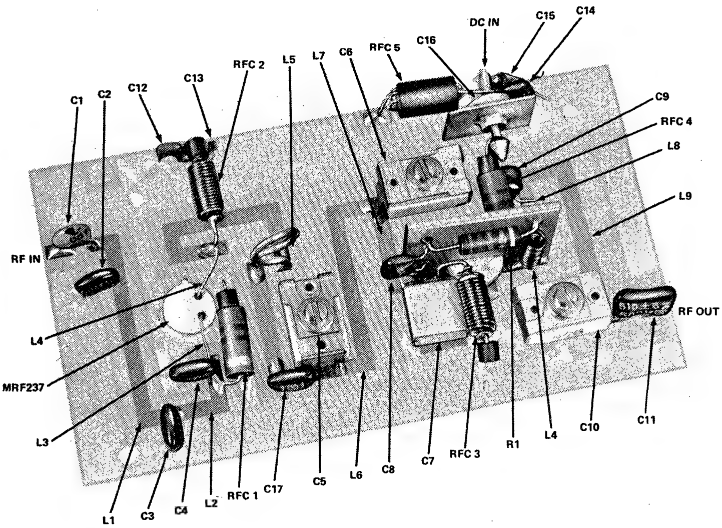



FIGURE 2. Top View of Amplifier Board with Parts Placement

## Printed Airline – the Key to Low Losses

The airlines used in this amplifier are inductors printed on the top side of a double-clad PC board. They are inexpensive and very reproducible.

In the areas below the lines on the opposite side of the board, the copper ground plane is removed with remaining ground plane providing a low-inductance system ground for the transistors and tuning capacitors. Eliminating the ground plane beneath the line sections improves the current distributions and lowers the $I^2R$ losses. Figure 1 is a photo showing an airline formed on a double-clad PC board. Figure 8 provides 1:1 top layout of the amplifier.

The line should be one-third centimeter from metallic areas such as the heatsink to prevent detuning. This is accomplished by mounting the board on spacers as shown in Figure 3.

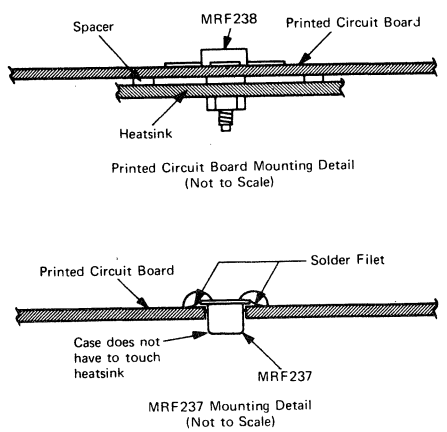



FIGURE 3

## The 4-Watt Gain Block

The first gain block utilizes the MRF237, a common-emitter TO-39 transistor. The block has 50-ohm input and output impedances, and provides at least 10 dB gain. The input has an exceptionally low (less than 1.5:1) SWR over the 140- to 175-MHz range. It needs no retuning when driven from a 50-ohm source. These benefits are provided by the block's input circuit which is essentially a low-pass filter designed to transform the line impedance down to that of the transistor.

The output circuit provides the tuning range needed to match the device over any segment of the band desired. The configuration of the output circuit is an L-section, low-pass matching network. It transforms the low and capacitive output to 50 ohms.

The first block's 4-watt, 50-ohm output can be switched independently through an attenuator into the output filter easily meeting the 1-watt requirement for a marine radio. Because of the common-emitter configuration, the TO-39 case can be directly soldered to the circuit board to provide RF grounding and eliminate the need

for additional heatsinks. Refer to EB-29 for details on this. Also see Figure 3.

### Interstage Match

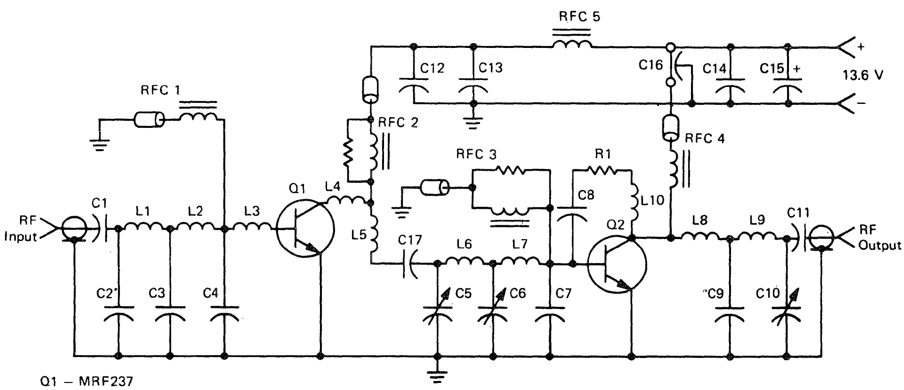
Both the output impedance of the MRF237 and the input impedance of the MRF238 are transformed to 50 ohms. This is done for two reasons: 1) the need for a 1-watt output suggests 50 ohms as a "natural" transform impedance, and 2) the high gain of both stages requires controlled coupling for maximum stability. Both the 100-pF blocking capacitor and 50-ohm interstage impedance contribute to the high stability of this chain by reducing the low-frequency coupling.

### The 30-Watt Gain Block

The device chosen for the output stage is the MRF238, a 9-dB, 30-watt product of Motorola's ongoing development work in transistor technology. MRF238 has higher gain than previous 30-watt parts as well as good stability; and, in order to realize all possible gain, careful attention must be paid to circuit grounding techniques.

A tunable, pi-section, low-pass filter is used to match the low-input impedance presented by MRF238. The capacitors closest to its base are low-loss UNELCO types used specifically for repeatability. ARCO 404s and 406s are the tunable capacitors.

If desired, the ARCOs on the amplifier's input may be replaced with appropriate Phillips TFE dielectric trimmers or E.F. Johnson air variables, which are also suitable for use on the output. Note, however, that the tuning range of the alternate capacitors is somewhat limited and will require different padding values to achieve a desired band split.




Q1 – MRF237
Q2 – MRF238
C1 – 0.001-μF, 50-V, Erie Disc
C2 – 39 pF Dipped MICA
C3 – 24 pF Dipped MICA
C4 – 91 pF Dipped MICA
C5 – 8.0–60 pF ARCO 404 Trimmer
C6, C10 – 15–115 pF ARCO 406 Trimmer
C7 – 250-pF and 100-pF UNELCO in Parallel
C8, 12, 14 – 0.1 μF, 50-Vdc, Erie Disc
C9 – 82-pF Dipped MICA
C11 – 500-pF Dipped MICA
C13 – 0.018-μF Chip
C15 – 1-μF, 35-Vdc, Tantalum
C16 – 680-pF Allen-Bradley Feedthrough
C17 – 100-pF Dipped MICA
R1 – 150-ohm, 1/2-Watt
RFC 1, 4 – 0.15-μH Molded Choke with Ferrite Bead Ferroxcube 5659065/4B

RFC 2 – 10 turns, No. 20 AWG, Enameled on 470-ohm, 1/2-W Resistor with Ferrite Bead Ferroxcube 5659065/4B
RFC 3 – 10 turns, No. 20 AWG, Enameled on 270-ohm, 1/2-W Resistor with Ferrite Bead Ferroxcube 5659065/4B
RFC 5 – Ferroxcube VK20020/4B
L1 – 1.3" X 0.1" (3.30 X 0.254 cm) Airline Inductor
L2 – 0.6" X 0.1" (1.52 X 0.254 cm) Airline Inductor
L3 – Base Lead Q1
L4 – Collector Lead Q1
L5 – Airline Inductor and 1-turn, No. 18 AWG, 0.25" (0.64 cm) I.D.
L6 – 1.9" X 0.1" (4.83 X 0.254 cm) Airline Inductor
L7 – 0.7" X 0.1" (1.78 X 0.254 cm) Airline Inductor
L8 – 0.9" X 0.1" (2.29 X 0.254 cm) Airline Inductor
L9 – 1.4" X 0.1" (3.56 X 0.254 cm) Airline Inductor
L10 – 10 turns, No. 20 AWG, Enameled Wire 0.62" (0.159 cm) I.D.

## Circuit Decoupling and Tune-Up

Some care is required in decoupling to achieve stability under adverse operating conditions due to the rather high gains of the stages. Both transistor bases are dc grounded through RF chokes and a Ferroxcube bead. The collectors, as well as the supply, are decoupled from each other with appropriate wirewound chokes, a VK200-20/4B and capacitors of suitable value.

Low-frequency gain in the MRF238 is degenerated with an LRC network between collector and base. This is most important under load mismatch or when driven by sources with high spurious content.

All trimmers are tuned for peak output at the center frequency of the range of interest. Broadbanding can be accomplished by tuning for equal peaks at the band edges of the desired frequency range using all three trimmers. Input drive requirements increase for significantly greater bandwidths.

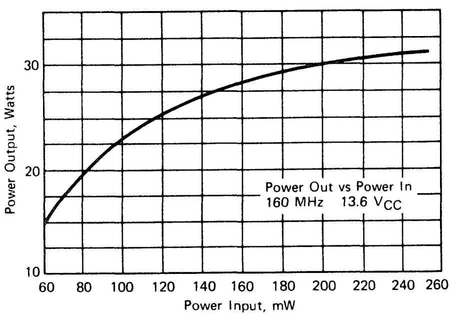



FIGURE 4. Power Out vs Power In at 160 MHz

**Data for MRF237/238 25-Watt Amp**
**Tuned across 144–160 MHz, 25 Watts, 13.5 VDC**

| Frequency MHz | $P_{In}$ mW | $I_C$ A | GPE dB | N % |
|---|---|---|---|---|
| 144 | 250 | 3.7 | 20.0 | 50 |
| 146 | 215 | 3.7 | 20.7 | 50 |
| 148 | 195 | 3.7 | 21.1 | 50 |
| 150 | 180 | 3.7 | 21.4 | 50 |
| 152 | 175 | 3.6 | 21.5 | 51 |
| 154 | 155 | 3.5 | 22.1 | 53 |
| 156 | 140 | 3.4 | 22.5 | 54 |
| 158 | 130 | 3.3 | 22.8 | 56 |
| 160 | 140 | 3.1 | 22.5 | 60 |

FIGURE 5(A)

## Chain Performance

Figures 4 and 5 depict overall amplifier performance and show that gain does not vary appreciably over typical bandsplits. A minimum of 20 dB of gain can be achieved with any combination of any MRF237/238 parts without need for further selection.

**Data for MRF237/238 25-Watt Amp**
**Tuned across 162–174 MHz, 25 Watts, 13.5 VDC**

| Frequency MHz | $P_{In}$ mW | $I_C$ A | GPE dB | N % |
|---|---|---|---|---|
| 162 | 195 | 3.5 | 21.1 | 53 |
| 164 | 175 | 3.4 | 21.5 | 54 |
| 166 | 165 | 3.3 | 21.8 | 56 |
| 168 | 160 | 3.2 | 21.9 | 58 |
| 170 | 170 | 3.1 | 21.7 | 60 |
| 172 | 250 | 2.8 | 20.0 | 66 |
| 174 | 250 | 2.8 | 20.0 | 66 |

FIGURE 5(B)

**Data for MRF237/238 Amp (140–180 MHz)**
**Retuning Each Frequency for 25 Watts, 13.5 VDC**

| Frequency MHz | $P_{In}$ mW | $I_C$ A | GPE dB | N % |
|---|---|---|---|---|
| 140 | 130 | 3.6 | 22.8 | 51 |
| 144 | 115 | 3.2 | 23.4 | 58 |
| 148 | 105 | 3.3 | 23.8 | 56 |
| 152 | 100 | 3.2 | 24.0 | 58 |
| 156 | 105 | 3.2 | 23.8 | 58 |
| 160 | 115 | 3.1 | 23.4 | 60 |
| 164 | 130 | 3.1 | 22.8 | 60 |
| 168 | 145 | 3.1 | 22.4 | 50 |
| 172 | 180 | 3.1 | 21.4 | 60 |
| 176 | 228 | 3.2 | 20.6 | 58 |
| 180 | 280 | 3.3 | 21.4 | 56 |

FIGURE 5(C)

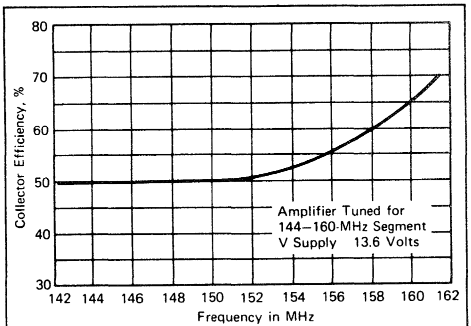



FIGURE 6. Frequency vs Collector Efficiency at 25-W Power Out, 142–176 MHz

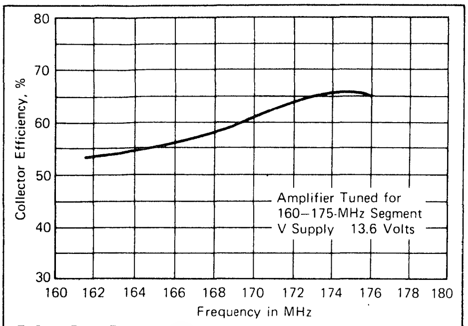



FIGURE 7. Frequency vs Collector Efficiency at 25-W Power Out, 160–176 MHz

The power amplifier stages described will operate into a 30:1 mismatch without damage. They will operate into a 10:1 mismatch without spurious generation, when run through a 0.5-dB insertion loss, low-pass filter. Pre-filter harmonics are greater than 25 dB down.

This amplifier meets the physical and electrical constraints of a reliable, low-cost, 30-watt power amplifier that is easy to build and tune. It uses the highest possible gain distributions and yet retains substantial margins of stability to ensure good performance in the field and minimal warranty costs. The need for elaborate VSWR shutdown circuits is virtually eliminated.

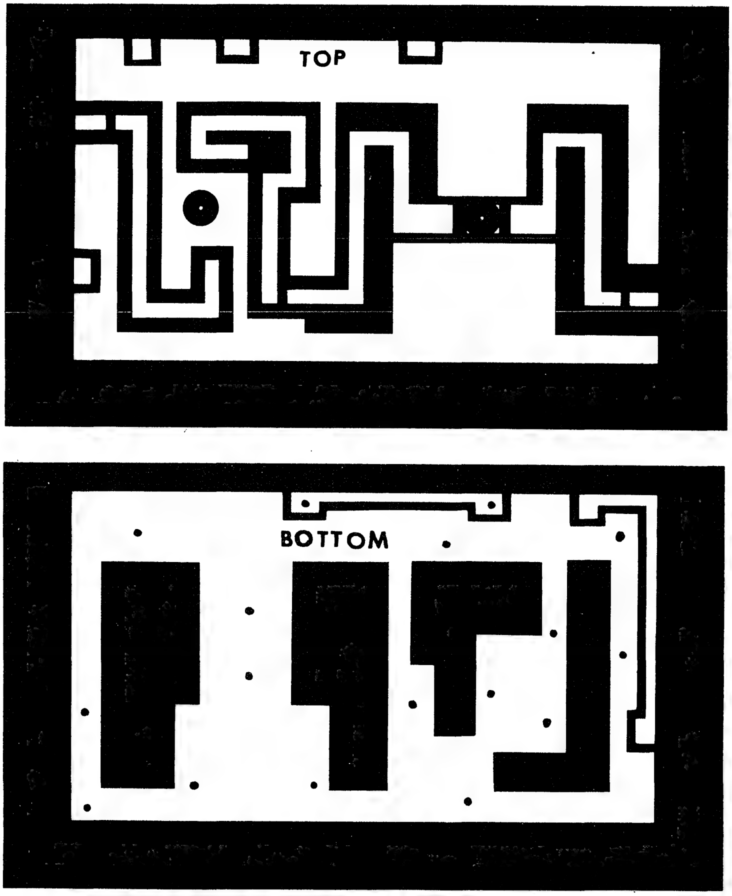
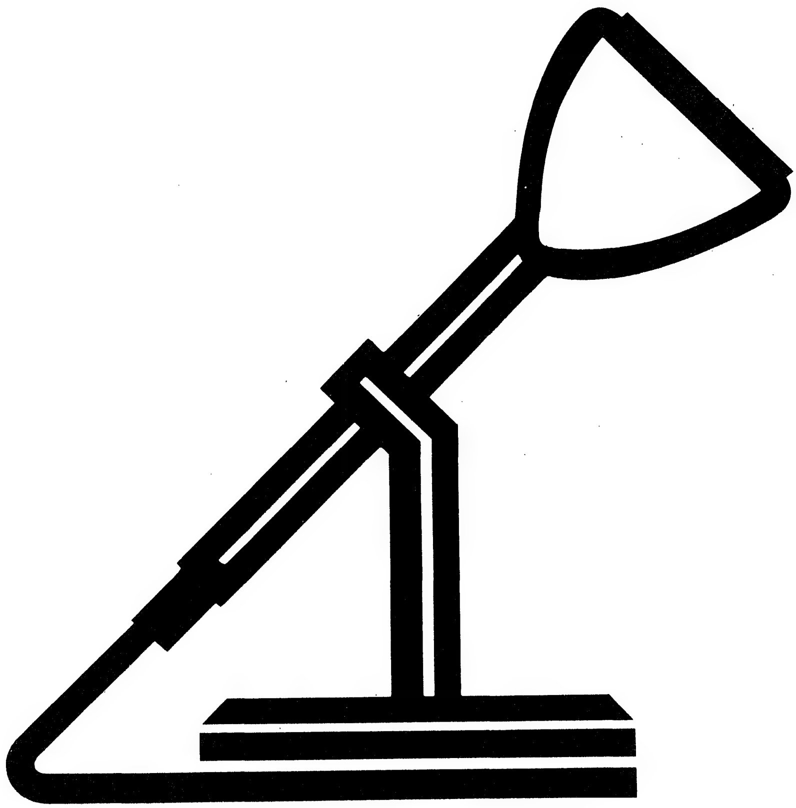



FIGURE 8. 1:1 Photomaster (Dots on Bottom View Indicate Rivet Placement)



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF207
# MRF208
# MRF209

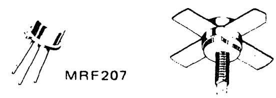
## The RF Line

### NPN SILICON RF POWER TRANSISTORS

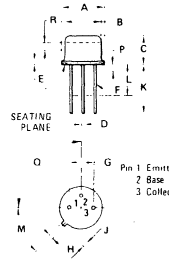
. . . designed for 12.5 Volt large-signal power amplifier applications in communications equipment operating at 220 MHz.

- Specified 12.5 Volt, 220 MHz Characteristics –
  Output Power = 1.0 W – MRF207
  10 W – MRF208
  25 W – MRF209
  Minimum Gain = 8.2 dB – MRF207
  10 dB – MRF208
  4.4 dB – MRF209
- Balanced-Emitter Construction to provide the designer with the device technology that assures ruggedness and resists transistor damage caused by load mismatch.

**1.0, 10, 25 WATTS – 220 MHz NPN SILICON RF POWER TRANSISTORS**




MRF207

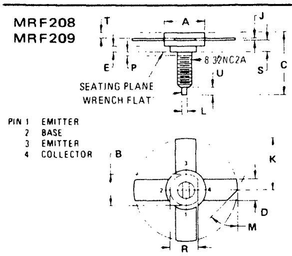



| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8 89 | 9 40 | 0 350 | 0 370 |
| B | 8.00 | 8 51 | 0.315 | 0.335 |
| C | 6 10 | 6 60 | 0.240 | 0.260 |
| D | 0 406 | 0 533 | 0.016 | 0.021 |
| E | 0 229 | 3.18 | 0.009 | 0.125 |
| F | 0 406 | 0.483 | 0 016 | 0 019 |
| G | 4 83 | 5.33 | 0 190 | 0 210 |
| H | 0.711 | 0 864 | 0 028 | 0.034 |
| J | 0 737 | 1.02 | 0.029 | 0.040 |
| K | 12 70 | - | 0 500 | - |
| L | 6 35 | - | 0 250 | |
| M | 45° NOM | | 45° NOM | |
| P | | 1.27 | - | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | | 0.100 | - |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

MRF208
MRF209




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | - | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

### MAXIMUM RATINGS

| Rating | Symbol | MRF207 | MRF208 | MRF209 | Unit |
|---|---|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | ← 18 → | | | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | ← 36 → | | | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | ← 4.0 → | | | Vdc |
| Collector Current – Continuous | $I_C$ | 0.4 | 2.0 | 4.0 | Adc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above 25°C | $P_D$ | 3.5<br>20 | 37.5<br>214 | 50<br>286 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | | | °C |
| Stud Torque (2) | – | – | 6.5 | | in. lb. |

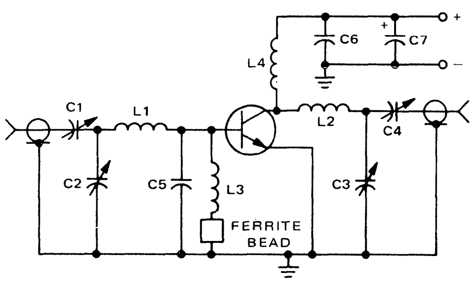
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.
(2) For Repeated Assembly use 5 in. lb.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | |
| Collector-Emitter Breakdown Voltage | | $BV_{CEO}$ | | | | Vdc |
| ($I_C$ = 5.0 mAdc, $I_B$ = 0) | MRF207 | | 18 | – | – | |
| ($I_C$ = 15 mAdc, $I_B$ = 0) | MRF208 | | 18 | – | – | |
| ($I_C$ = 20 mAdc, $I_B$ = 0) | MRF209 | | 18 | – | – | |
| Collector-Base Breakdown Voltage | | $BV_{CBO}$ | | | | Vdc |
| ($I_C$ = 2.0 mAdc, $I_E$ = 0) | MRF207 | | 36 | – | – | |
| ($I_C$ = 5.0 mAdc, $I_E$ = 0) | MRF208 | | 36 | – | – | |
| ($I_C$ = 10 mAdc, $I_E$ = 0) | MRF209 | | 36 | – | – | |
| Emitter-Base Breakdown Voltage | | $BV_{EBO}$ | | | | Vdc |
| ($I_E$ = 1.0 mAdc, $I_C$ = 0) | MRF207 | | 4.0 | – | – | |
| ($I_E$ = 2.5 mAdc, $I_C$ = 0) | MRF208 | | 4.0 | – | – | |
| ($I_E$ = 5.0 mAdc, $I_C$ = 0) | MRF209 | | 4.0 | – | – | |
| Collector Cutoff Current | | $I_{CBO}$ | | | | mAdc |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | MRF207 | | – | – | 0.1 | |
| | MRF208 | | – | – | 0.25 | |
| | MRF209 | | – | – | 0.5 | |
| **ON CHARACTERISTICS** | | | | | | |
| DC Current Gain | | $h_{FE}$ | | | | – |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | MRF207 | | 5.0 | – | – | |
| ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | MRF208 | | 5.0 | – | – | |
| ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | MRF209 | | 5.0 | – | – | |
| **FUNCTIONAL TESTS** | | | | | | |
| Common-Emitter Amplifier Power Gain | | $G_{PE}$ | | | | dB |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W, f = 220 MHz) | MRF207 | | 8.2 | 12.5 | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, f = 220 MHz) | MRF208 | | 10 | 12.5 | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 220 MHz) | MRF209 | | 4.4 | 5.2 | – | |
| Input Impedance | | $Z_{in}$ | | | | Ohms |
| ($P_{out}$ = 1.0 W, f = 220 MHz) | MRF207 | | – | 10-j11.5 | – | |
| ($P_{out}$ = 10 W, f = 220 MHz) | MRF208 | | – | 1.4+j1.4 | – | |
| ($P_{out}$ = 25 W, f = 220 MHz) | MRF209 | | – | 1.4+j1.8 | – | |
| Output Impedance | | $Z_{out}$ | | | | Ohms |
| ($P_{out}$ = 1.0 W, f = 220 MHz) | MRF207 | | – | 32 - j41 | – | |
| ($P_{out}$ = 10 W, f = 220 MHz) | MRF208 | | – | 5.7 - j1.3 | – | |
| ($P_{out}$ = 25 W, f = 220 MHz) | MRF209 | | – | 3.9 - j0.2 | – | |

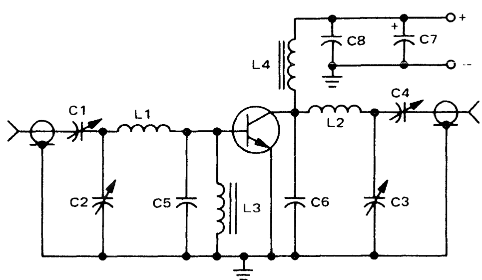
**220 MHz TEST CIRCUIT**

FIGURE 1 – MRF207




| | | |
|---|---|---|
| C1 | 2.0 - 50 pF | ARCO 461 |
| C2, C4 | 5.0 - 80 pF | ARCO 462 |
| C3 | 1.5 - 15 pF | ARCO 460 |
| C5 | 40 pF | |
| C6 | 1000 pF | |
| C7 | 5.0 μF | TANTALUM |
| L1 | 1 Turn, #20 AWG, 1/4" ID | |
| L2 | 4 Turns, #20 AWG, 1/4 ID | |
| L3, L4 | 15 μH RFC | |

FIGURE 2 – MRF208, MRF209




| | | |
|---|---|---|
| C1, C2, C3, C4 | 5.0 - 80 pF | ARCO 462 |
| C5, C6 | 100 pF | |
| C7 | 10 μF | TANTALUM |
| C8 | 1000 pF | |
| L1 | #14 AWG, 1¼" Long, Straight | |
| L2 | 1 Turn, #14 AWG, 3/8" ID | |
| L3, L4 | RFC VK200 | |

## OUTPUT POWER versus INPUT POWER

($V_{CC}$ = 12.5 Vdc, f = 220 MHz)

FIGURE 3 – MRF207

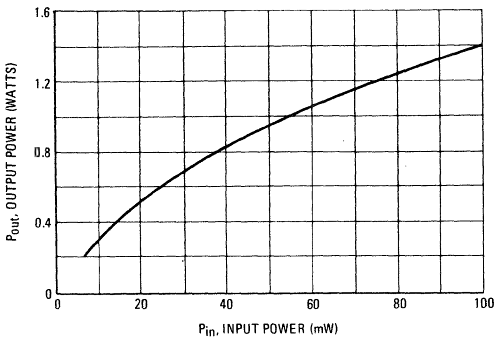



FIGURE 4 – MRF208

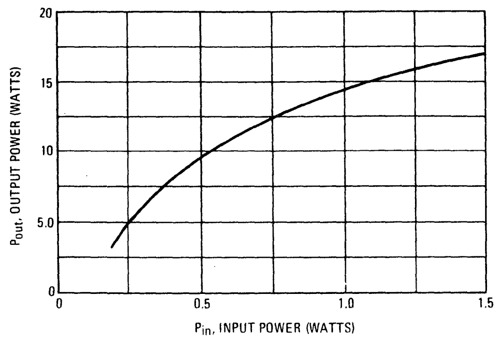



FIGURE 5 – MRF209

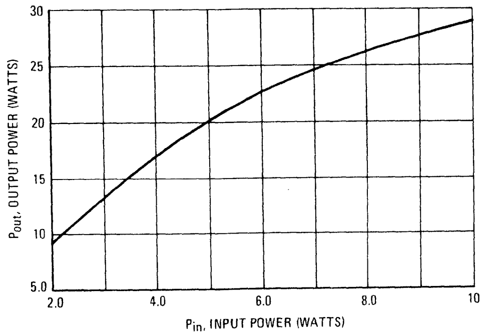



FIGURE 6 – 220-MHz, 25-WATT AMPLIFIER

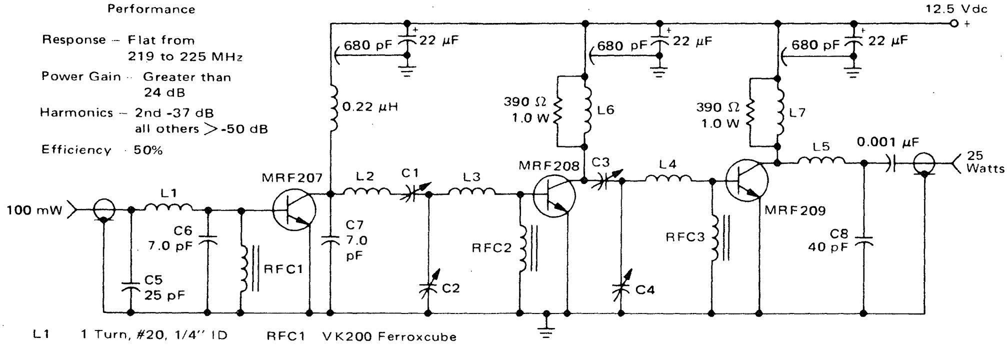
Performance

Response – Flat from 219 to 225 MHz

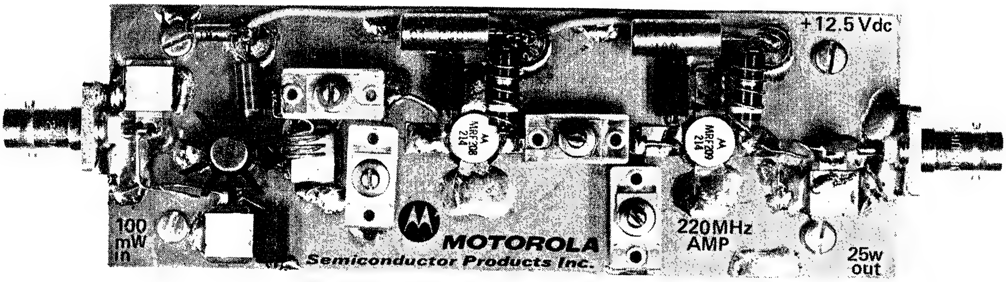
Power Gain – Greater than 24 dB

Harmonics – 2nd -37 dB, all others >-50 dB

Efficiency – 50%




| | | | | | |
|---|---|---|---|---|---|
| L1 | 1 Turn, #20, 1/4" ID | RFC1 | VK200 Ferroxcube | C1 | 2.0-25 pF, ARCO 421 or equivalent |
| L2 | 3 Turns, #20, 1/4" ID | RFC2 | VK200 Ferroxcube | C2,C3,C4 | 7.0-100 pF, ARCO, 423 or equivalent |
| L3 | 1/3 Turn, #16, 3/8" ID | RFC3 | VK200 Ferroxcube | C8 | Underwood or equivalent capacitor which is capable of high current without undue heating. |
| L4 | 1/3 Turn, #18, 1/4" ID | | | | |
| L5 | 1 Turn, #20, 1/8" ID | | | | |
| L6,L7 | 5 Turns, #20, 1/4" ID | | | | |


+12.5 Vdc
MRF208
214
MRF209
214
100 mW in
MOTOROLA
Semiconductor Products Inc.
220MHz AMP
25w out

**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

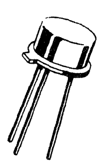
# MRF225

## The RF Line

1.5 W – 225 MHz

**RF POWER TRANSISTOR**

**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

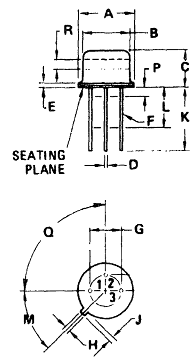
. . . designed for 12.5 Volt large-signal power amplifier applications in communication equipment operating at 225 MHz. Ideally suited for Class E citizens band radio.

- Specified 12.5 Volt, 225 MHz Characteristics –
  Output Power = 1.5 Watts
  Minimum Gain = 9.0 dB
  Efficiency = 50%
- Characterized With Series Equivalent Large-Signal Impedance Parameters

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.25 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 3.5<br>0.02 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF amplifiers.



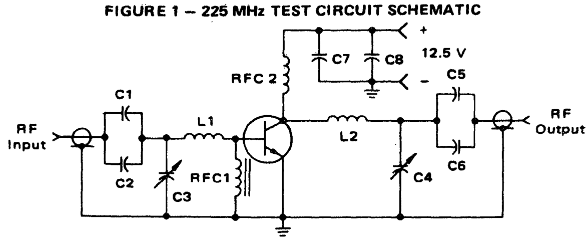

STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

FIGURE 1 – 225 MHz TEST CIRCUIT SCHEMATIC




| | |
|---|---|
| C1,2,5 | 50 pF Dipped Mica |
| C3 | 1.5-20 pF ARCO 402 |
| C4 | 4.0-40 pF ARCO 403 |
| C6 | 100 pF Dipped Mica |
| C7 | 1000 pF UNELCO |
| C8 | 1.0 µF 35 V Tantalum |
| L1 | 0.6 Inch #18 AWG. |
| L2 | 2 Turns x 0.25 inch ID #18 AWG |
| RFC 1 | Ferroxcube VK200 |
| RFC 2 | 2.2 µH Molded Choke |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 100 | μAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 15 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 8.0 | pF |
| **FUNCTIONAL TEST** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 1.5 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $G_{PE}$ | 9.0 | – | dB |
| Collector Efficiency ($P_{out}$ = 1.5 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $\eta$ | 50 | – | % |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

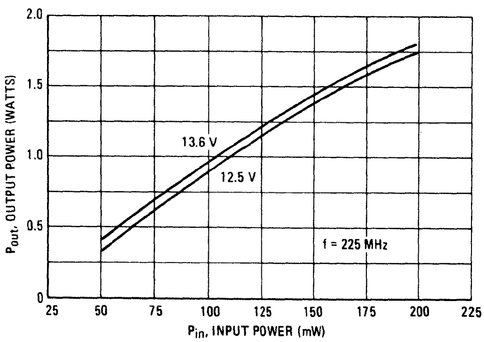
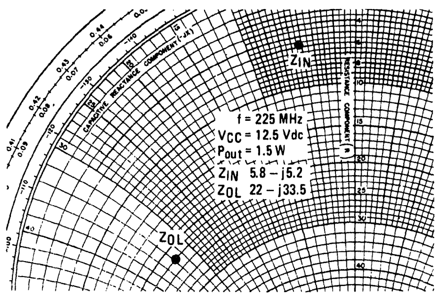



FIGURE 3 – SERIES EQUIVALENT IMPEDANCE



# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

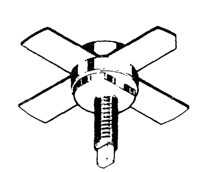
# MRF226

## The RF Line

13 W – 225 MHz

**RF POWER TRANSISTOR**

**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

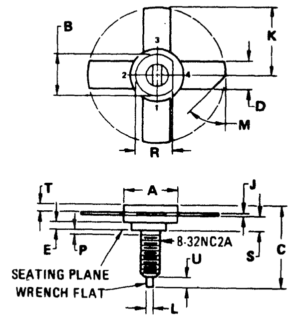
. . . . designed for 12.5 Volt large-signal power amplifier applications in communication equipment operating at 225 MHz. Ideally suited for Class E citizens band radio.

- Specified 12.5 Volt, 225 MHz Characteristics –
  Output Power = 13 Watts
  Minimum Gain = 9.0 dB
  Efficiency = 50%
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Designed to Withstand Load Mismatch at all Phase Angles with 20:1 VSWR

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 18 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 2.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above 25°C | $P_D$ | 45<br>257 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | In. Lb. |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF amplifiers.
(2) For repeated assembly, use 5 In. Lb.

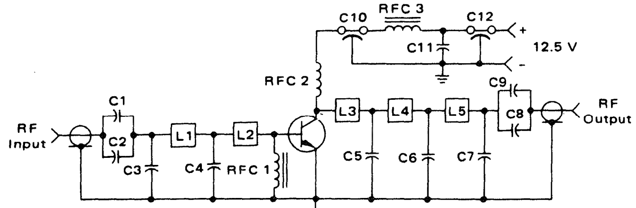



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.40 | 9.78 | 0.370 | 0.385 |
| B | 8.13 | 8.38 | 0.320 | 0.330 |
| C | 17.02 | 20.07 | 0.670 | 0.790 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.78 | – | 0.070 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| L | 1.40 | 1.78 | 0.055 | 0.070 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| R | 7.59 | 7.80 | 0.299 | 0.307 |
| S | 4.01 | 4.52 | 0.158 | 0.178 |
| T | 2.11 | 2.54 | 0.083 | 0.100 |
| U | 2.49 | 3.35 | 0.098 | 0.132 |

145A-09

FIGURE 1 – 225 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1,2,8,9 | 18 pF Chip Cap 50 V | RFC 2 | 0.15 µH Molded Choke |
| C3 | 15 pF UNELCO | L1 | 0.15 x 3.15 inch Microstrip |
| C4,5 | 80 pF UNELCO | L2 | 0.15 x 0.55 inch Microstrip |
| C6 | 25 pF UNELCO | L3 | 0.15 x 1.4 inch Microstrip |
| C7 | 7.0 pF UNELCO | L4 | 0.15 x 2.35 inch Microstrip |
| C10,12 | 680 pF Feedthru ALLEN BRADLEY | L5 | 0.15 x 0.5 inch Microstrip |
| C11 | 1.0 µF, 35 V Tantalum | | Board is G10 3 x 5 x 0.062 inch |
| RFC 1,3 | Ferroxcube VK200 | | $\epsilon_R = 5$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector Emitter Breakdown Voltage ($I_C$ = 15 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 18 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.5 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 0.25 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 250 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | – |
| **FUNCTIONAL TEST** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 13 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $G_{PE}$ | 9.0 | – | dB |
| Collector Efficiency ($P_{out}$ = 13 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $\eta$ | 50 | – | % |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

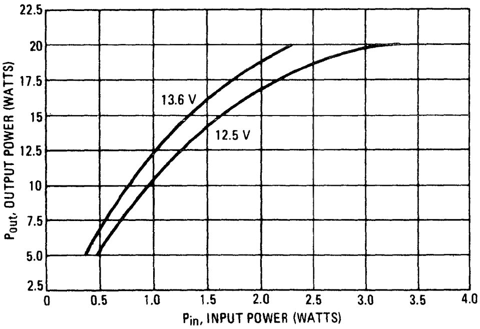
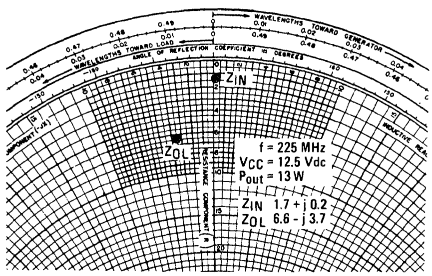



FIGURE 3 – SERIES EQUIVALENT IMPEDANCE



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF227

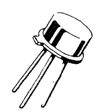
## The RF Line

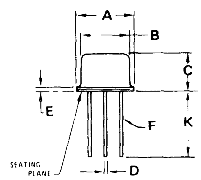
3 W – 225 MHz
RF POWER
TRANSISTOR
NPN SILICON

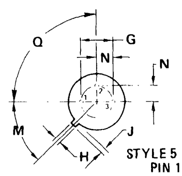
## NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt large-signal power amplifier applications in communication equipment operating at 225 MHz. Ideally suited for Class E citizens band radio.

- Specified 12.5 Volt, 225 MHz Characteristics –
  Output Power = 3.0 Watts
  Minimum Gain = 13.5 dB
  Efficiency = 60%
- Characterized With Series Equivalent Large-Signal Impedance Parameters
- Grounded Emitter TO-39 Package for High Gain and Excellent Heat Dissipation
- Replaces Medium Power Stud Mount Devices






STYLE 5
PIN 1. COLLECTOR
2. BASE
3. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |

CASE 79-03

## MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Collector Current – Continuous | $I_C$ | 400 | mAdc |
| Total Power Dissipation @ $T_C = 25^oC$<br>Derate above 25°C | $P_D$ | 5.0<br>28.5 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | $I_{CES}$ | – | – | 10 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 15 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 3.0 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $G_{PE}$ | 13.5 | 15 | – | dB |
| Collector Efficiency ($P_{out}$ = 3.0 W, $V_{CC}$ = 12.5 Vdc, f = 225 MHz) | $\eta$ | 60 | – | – | % |

FIGURE 1 – 225 MHz TEST CIRCUIT

| | |
|---|---|
| C1,C2,C3,C4 | ARCO 420 |
| C5 | 1000 pF, UNELCO |
| C6 | 0.047 pF, ERIE |
| C7 | 1.0 pF, TANTALUM |
| L1 | #18 AWG, 1" Wire Length |
| L2 | VK200-4 Ferroxcube |
| L3 | 1 Turn, #18 AWG, 1/4" ID x 2" Wire Length |
| L4 | 0.15 μH DELEVAN Molded Choke |

Board – Glass Teflon, $\epsilon_R$ = 2.56, t = 0.062"
Input/Output Connectors – Type N

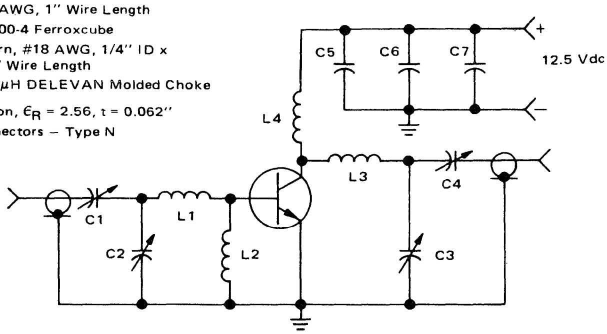


FIGURE 2 – INPUT POWER versus OUTPUT POWER – 12.5 V

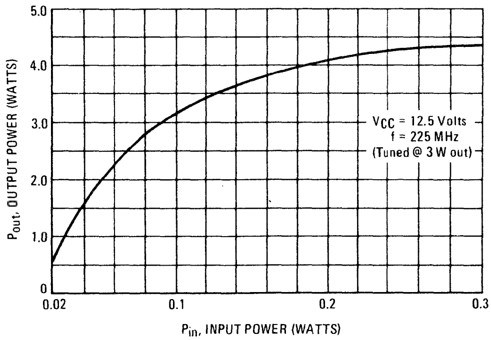



FIGURE 3 – INPUT POWER versus OUTPUT POWER – 13.6 V

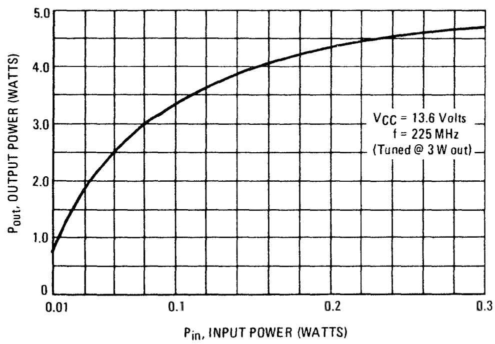



FIGURE 4 – INPUT POWER versus OUTPUT POWER – 7.5 V

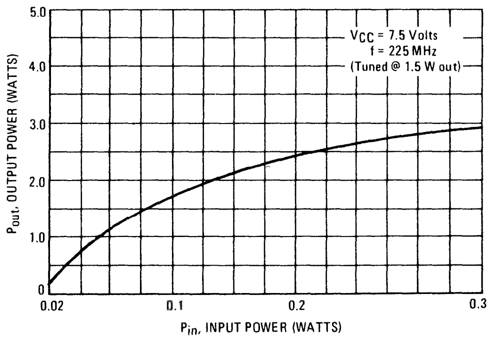



FIGURE 5 – OUTPUT POWER versus SUPPLY VOLTAGE

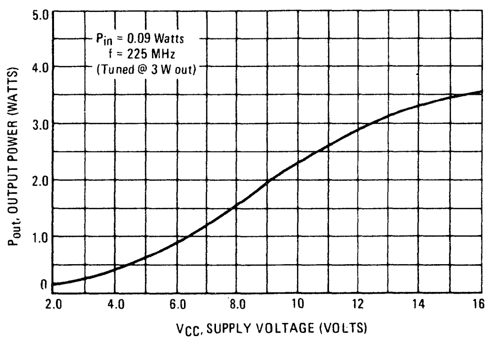
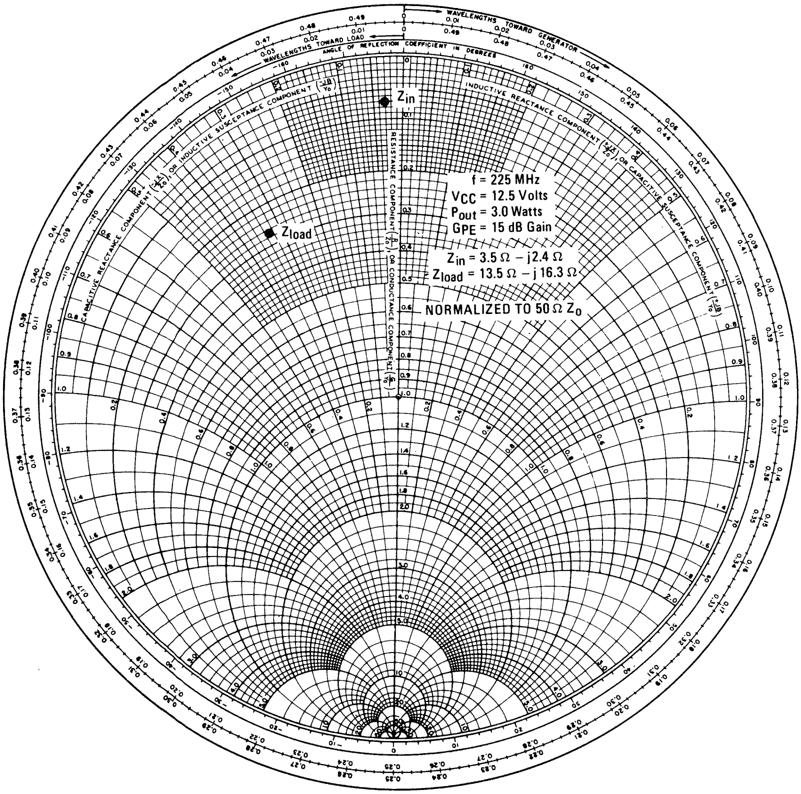
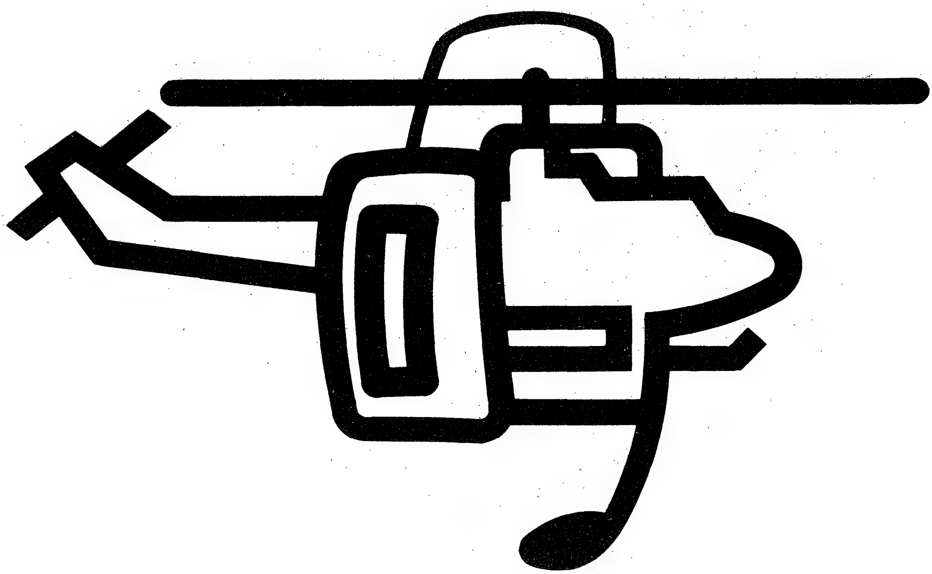


FIGURE 6 – SERIES EQUIVALENT IMPEDANCE





# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N3866

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

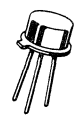
. . . designed for amplifier and oscillator applications in military and industrial equipment. Suitable for use as output, driver or pre-driver stages in VHF and UHF equipment.

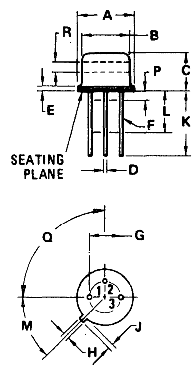
- Specified 400 MHz, 28 Vdc Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 10 dB
  Efficiency = 45%
- Large Signal Series Equivalent Impedances
- S-Parameter Characterization

**1.0 W – 400 MHz**

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**






| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

CASE 79-02
TO-39

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 55 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.4 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 5.0<br>28.6 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

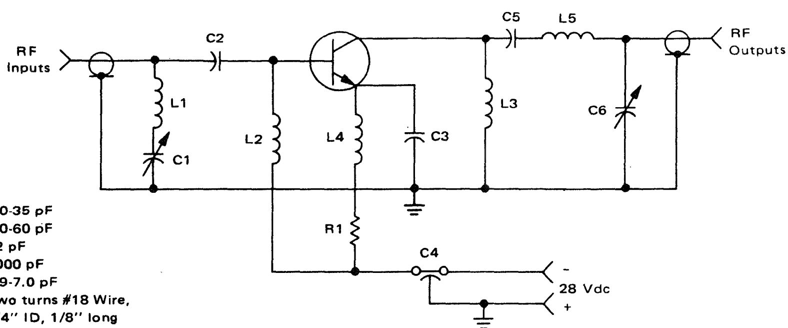
*Indicates JEDEC Registered Data

*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 30 | – | Vdc |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 10 Ω) | $V_{CER(sus)}$ | 55 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | 0.02 | mAdc |
| Emitter Cutoff Current ($V_{BE}$ = 3.5 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | 0.1 | mAdc |
| Collector Cutoff Current<br>($V_{CE}$ = 30 Vdc, $V_{BE}$ = -1.5 Vdc (Rev.), $T_C$ = 200°C)<br>($V_{CE}$ = 55 Vdc, $V_{BE}$ = -1.5 Vdc (Rev.) | $I_{CEX}$ | <br>–<br>– | <br>5.0<br>0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain<br>($I_C$ = 360 mAdc, $V_{CE}$ = 5.0 Vdc)<br>($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0<br>10 | –<br>200 | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 20 mAdc) | $V_{CE(sat)}$ | – | 1.0 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 500 | – | MHz |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | pF |
| **FUNCTIONAL TESTS** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $G_{PE}$ | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $\eta$ | 45 | – | % |

*Indicates JEDEC Registered Data.

FIGURE 1 – 400 MHz TEST CIRCUIT SCHEMATIC




C1: 3.0-35 pF
C2,C5: 8.0-60 pF
C3: 12 pF
C4: 1000 pF
C6: 0.9-7.0 pF
L1: Two turns #18 Wire, 1/4" ID, 1/8" long
L2: FERRITE RF Choke, One Turn, z = 450 Ohms
L3,L4: RF Choke, 0.1 μH
L5: 2-3/4 Turns, #18 Wire, 1/4" ID, 3/16" long
R1: 5.6 Ohms

FIGURE 2 – POWER OUTPUT versus FREQUENCY (Class C)

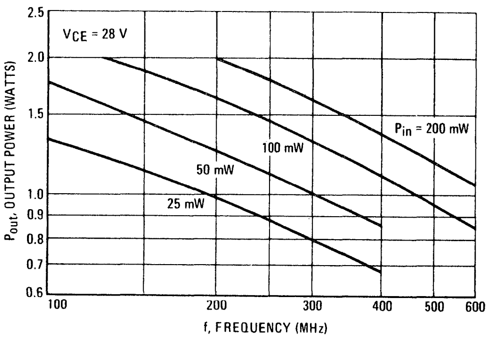



FIGURE 3 – CURRENT-GAIN – BANDWIDTH PRODUCT

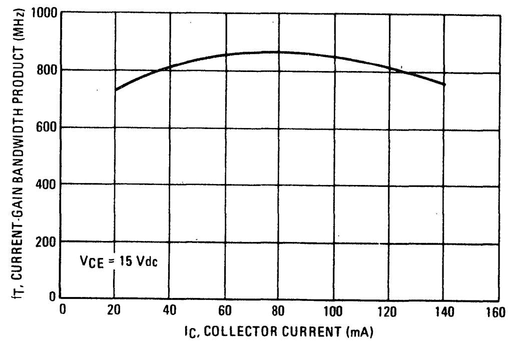



FIGURE 4 – COLLECTOR-BASE TIME CONSTANT

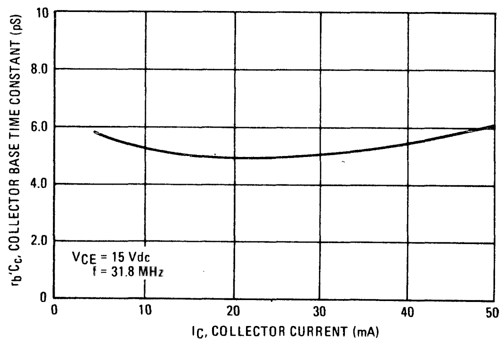



FIGURE 5 – OUTPUT CAPACITANCE

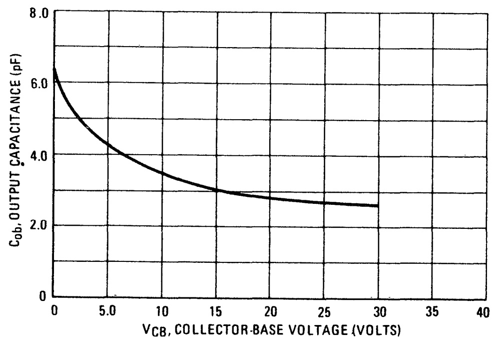



FIGURE 6 – OUTPUT POWER versus INPUT POWER (CLASS C)

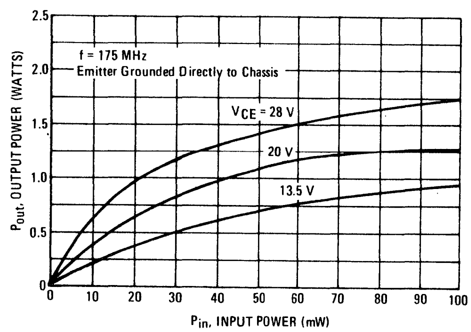



FIGURE 7 – SMALL-SIGNAL CURRENT GAIN

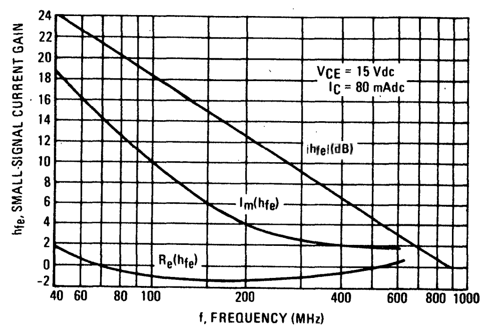


FIGURE 8 – LARGE-SIGNAL SERIES EQUIVALENT IMPEDANCES

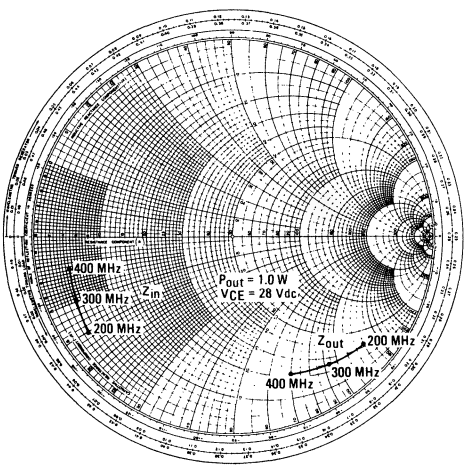



FIGURE 9 – $S_{11}$ AND $S_{22}$ versus FREQUENCY

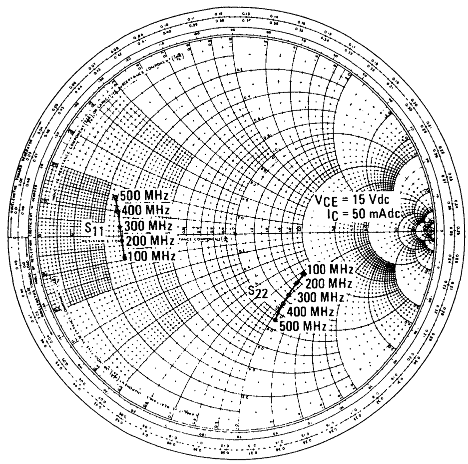



FIGURE 10 – $S_{21}$ versus FREQUENCY

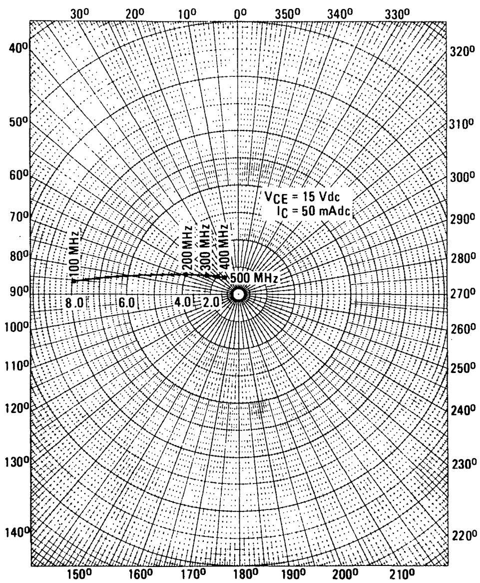
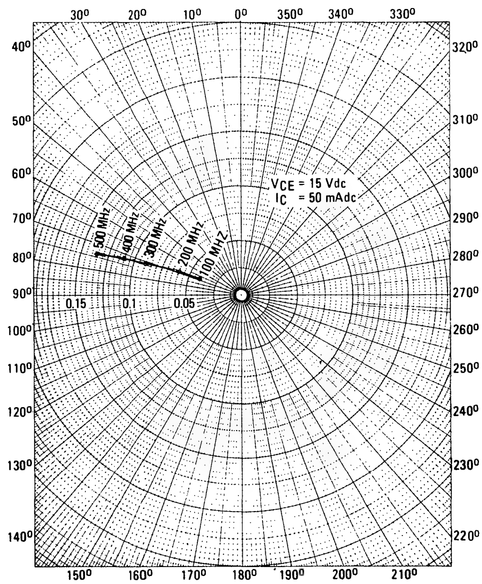



FIGURE 11 – $S_{12}$ versus FREQUENCY



**MOTOROLA Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N4428

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

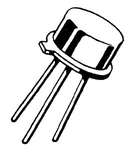
. . . designed primarily for use in large signal VHF and UHF amplifier output stages in military and industrial communications applications.

- Specified 28 Volt, 500 MHz Characteristics –
  Output Power = 750 mW
  Typical Gain = 10 dB
  Efficiency = 35%

**0.75 W – 500 MHz**

**RF POWER TRANSISTOR**

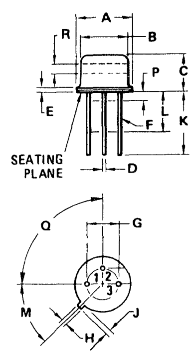
**NPN SILICON**



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 55 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 425 | mAdc |
| Base Current – Continuous | $I_B$ | 150 | mAdc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 3.5<br>20 | Watts<br>$mW/^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

*Indicates JEDEC Registered Data.



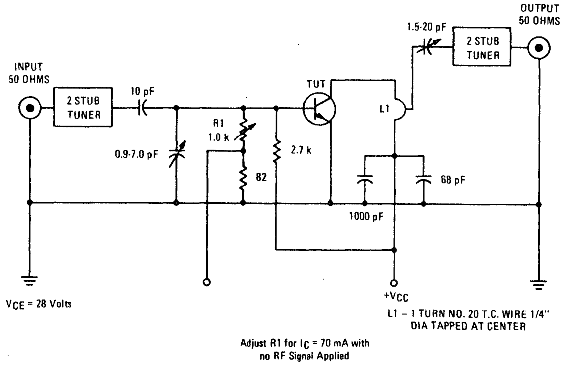

STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

**CASE 79-02**
**TO-39**

**FIGURE 1 – 500 MHz TEST CIRCUIT**



*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO(sus)}$ | 35 | – | – | Vdc |
| Collector-Emitter Sustaining Voltage ($I_C$ = 20 mAdc, $R_{BE}$ = 10 ohms) | $BV_{CER(sus)}$ | 55 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 55 Vdc, $V_{BE(on)}$ = -1.5 Vdc) | $I_{CEX}$ | – | – | 1.0 | mAdc |
| Emitter Cutoff Current ($V_{EB}$ = 3.5 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain | $h_{FE}$ | | | | – |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | | 20 | – | 200 | |
| ($I_C$ = 400 mAdc, $V_{CE}$ = 5.0 Vdc) | | 5.0 | – | – | |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 20 Vdc, f = 200 MHz) | $f_T$ | 700 | 1000 | – | MHz |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 1.2 | 3.5 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Power Input (Figure 1) ($P_{out}$ = 750 mW, $V_{CE}$ = 28 Vdc, $R_S$ = 50 Ohms, f = 500 MHz) | $P_{in}$ | – | – | 75 | mW |
| Collector Efficiency (Figure 1) ($P_{out}$ = 750 mW, $V_{CE}$ = 28 Vdc, $R_S$ = 50 Ohms, f = 500 MHz) | $\eta$ | 35 | – | – | % |

*Indicates JEDEC Registered Data.

FIGURE 2 – CURRENT-GAIN–BANDWIDTH PRODUCT

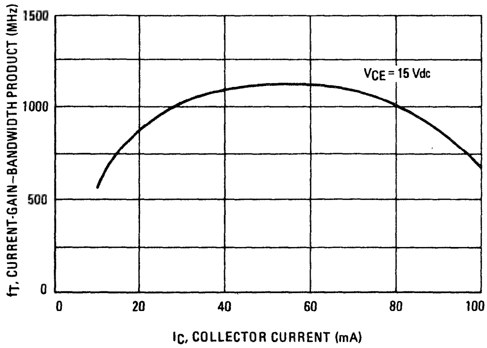
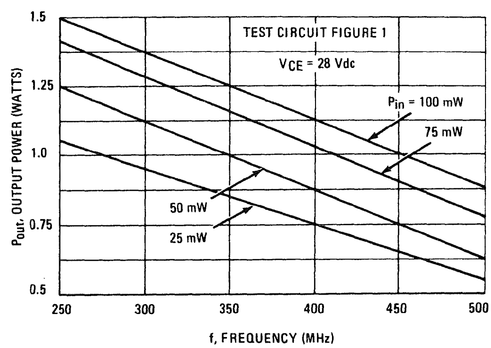



FIGURE 3 – OUTPUT POWER versus FREQUENCY



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5160

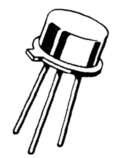
## The RF Line

**PNP SILICON AMPLIFIER TRANSISTOR**

### PNP SILICON RF POWER TRANSISTORS

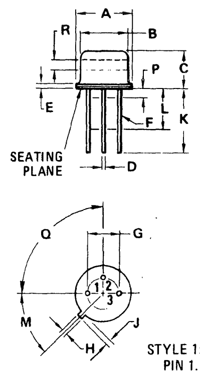
. . . designed for amplifier, frequency multiplier or oscillator applications in military and industrial equipment. Suitable for use as Class A, B, or C output driver, or pre-driver stages in VHF and UHF.

- High Power Gain — $G_{PE}$ = 8.0 dB (Min) @ f = 400 MHz, 14.5 dB (Typ) @ 175 MHz — No Emitter Tuning
- Power Output — $P_{out}$ = 1.0 Watt (Min) @ f = 400 MHz = 1.5 Watt (Typ) @ f = 175 MHz
- Resists Burnout When Load is Shorted or Opened
- Designed for Use in Complementary Circuits with 2N3866



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 40 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.0 | Vdc |
| Collector Current | $I_C$ | 0.4 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J$, $T_{stg}$ | -65 to +200 | °C |




STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO(sus)}$ | 40 | - | - | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | - | - | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $I_B$ = 0) | $I_{CEO}$ | - | - | 20 | μAdc |
| Collector Cutoff Current ($V_{CE}$ = 60 Vdc, $V_{BE}$ = 0) | $I_{CES}$ | - | - | 0.1 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 28 Vdc, $I_E$ = 0) | $I_{CBO}$ | - | - | 1.0 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | - | - | - |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain–Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 500 | 900 | - | MHz |
| Collector-Base Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{cb}$ | - | 2.5 | 4.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CE}$ = 28 Vdc, $P_{in}$ = 0.16 Watt, f = 400 MHz) | $G_{PE}$ | 8.0 | 8.8 | - | dB |
| ($V_{CE}$ = 28 Vdc, $P_{in}$ = 50 mW, f = 175 MHz) | | - | 14.5 | - | |
| Power Output ($V_{CE}$ = 28 Vdc, $P_{in}$ = 0.16 Watt, f = 400 MHz) | $P_{out}$ | 1.0 | 1.2 | - | Watt |
| ($V_{CE}$ = 28 Vdc, $P_{in}$ = 50 mW, f = 175 MHz) | | - | 1.4 | - | |
| Collector Efficiency ($V_{CE}$ = 28 Vdc, $P_{in}$ = 0.16 Watt, f = 400 MHz) | $\eta$ | 45 | 55 | - | % |

**FIGURE 1 — 400-MHz TEST CIRCUIT**

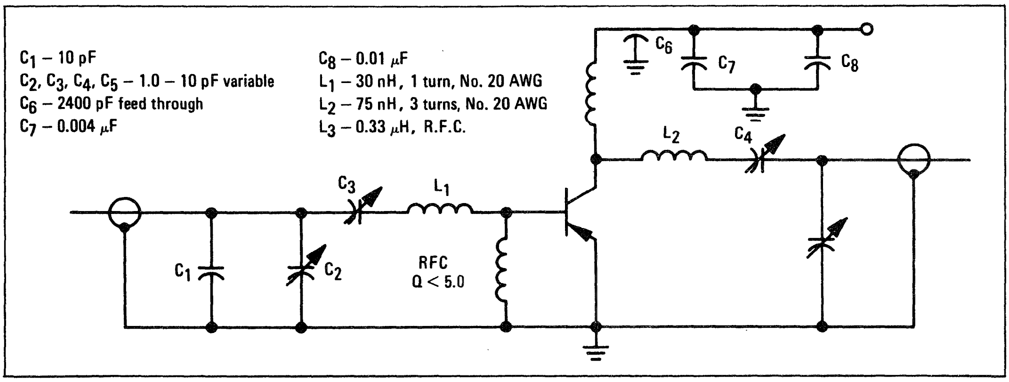


FIGURE 2 – POWER OUTPUT versus FREQUENCY

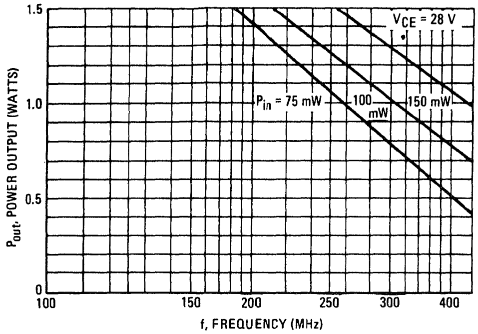



FIGURE 3 – POWER OUTPUT versus POWER INPUT

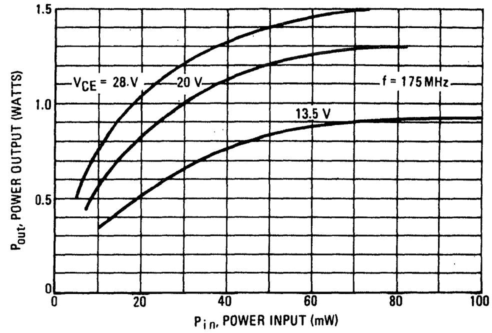



FIGURE 4 – PARALLEL INPUT IMPEDANCE versus FREQUENCY

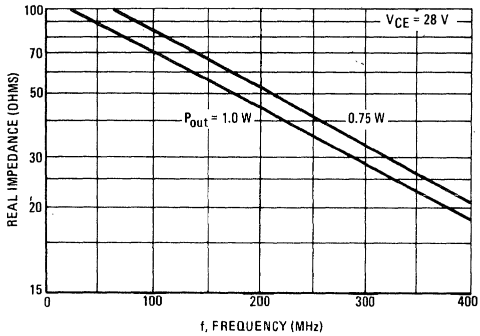



FIGURE 5 – PARALLEL INPUT IMPEDANCE versus FREQUENCY

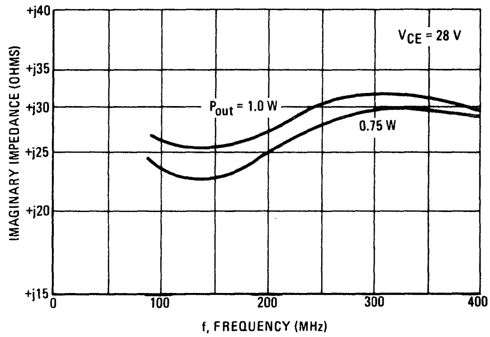



FIGURE 6 – PARALLEL OUTPUT CAPACITANCE versus FREQUENCY

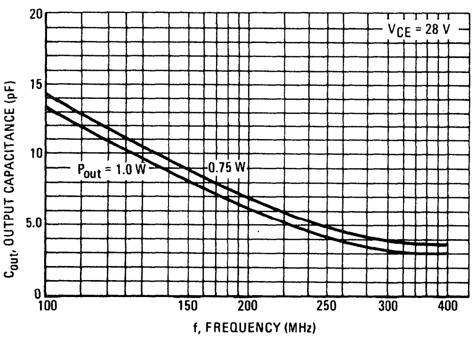



FIGURE 7 – CURRENT-GAIN–BANDWIDTH PRODUCT versus COLLECTOR CURRENT

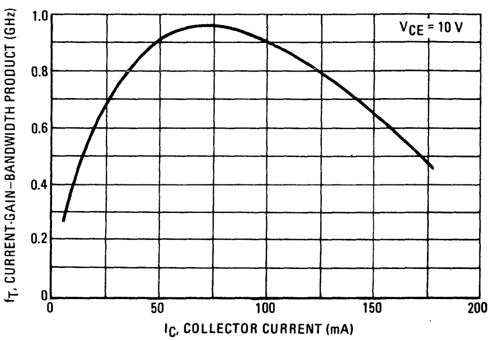


**FIGURE 8 – 2N5160 300-MHz COMPLEMENTARY POWER OUTPUT CIRCUIT**

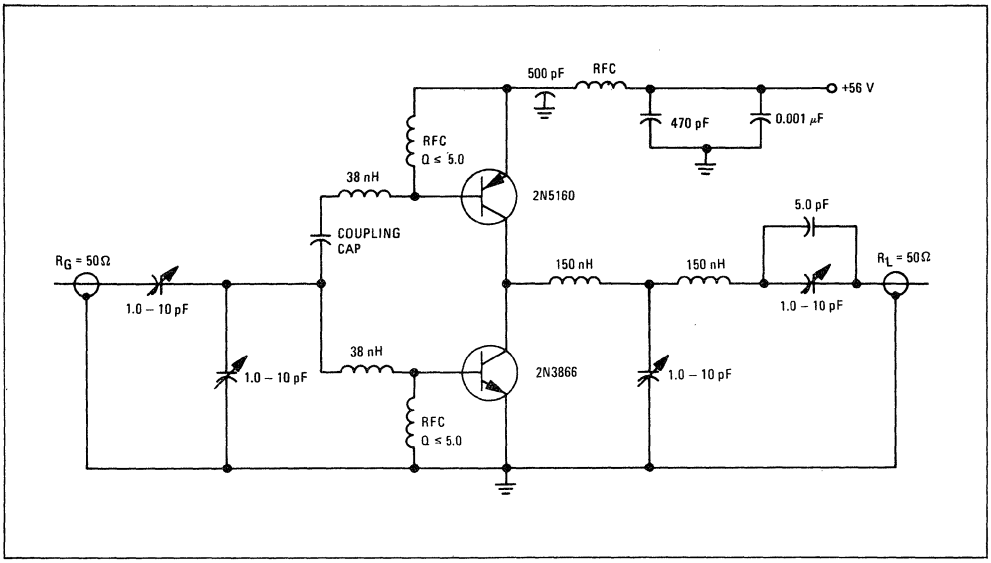
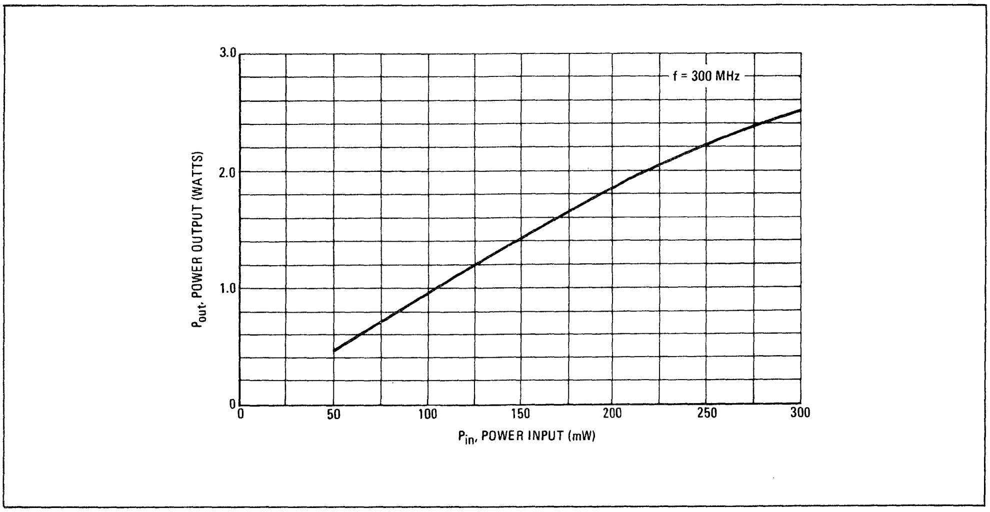



**FIGURE 9 – COMPLEMENTARY CIRCUIT – POWER OUTPUT versus POWER INPUT**



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6439

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

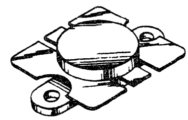
. . . designed primarily for wideband large-signal output amplifier stages in the 225-400 MHz frequency range.

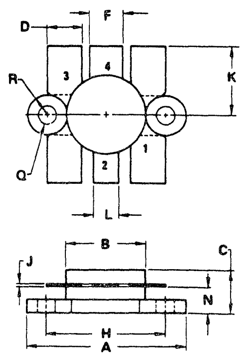
- Guaranteed Performance in 225–400 MHz Broadband Amplifier @ 28 Vdc
  Output Power = 60 Watts over 225–400 MHz Band
  Minimum Gain = 7.8 dB @ 400 MHz
- Built-In Matching Network for Broadband Operation Using Double Match Technique
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability Applications

**60 W – 225–400 MHz**

**CONTROLLED "Q"
BROADBAND RF POWER
TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above $25^{\circ}C$ | $P_D$ | 146<br>0.83 | Watts<br>$W/^{\circ}C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^{\circ}C$ |

### THERMAL CHARACTERISTICS

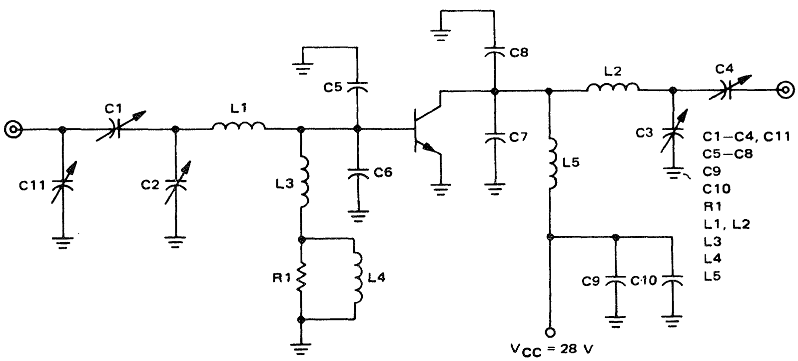
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.2 | $^{\circ}C/W$ |

(1)These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 2.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 100 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 67 | 75 | pF |
| **BROADBAND FUNCTIONAL TESTS** (Figure 6) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 60 W, f = 225–400 MHz) | $G_{PE}$ | 7.8 | 8.5 | – | dB |
| Electrical Ruggedness ($P_{out}$ = 60 W, $V_{CC}$ = 28 Vdc, f = 400 MHz, VSWR 30:1 all phase angles) | – | No Degradation in $P_{out}$ | | | – |
| **NARROW BAND FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 60 W, f = 400 MHz) | $G_{PE}$ | 7.8 | 10 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 60 W, f = 400 MHz) | $\eta$ | 55 | – | – | % |

**FIGURE 1 – 400 MHz TEST AMPLIFIER (NARROW BAND)**




| | |
|---|---|
| C1–C4, C11 | 4–40 pF |
| C5–C8 | 33 pF |
| C9 | 1000 pF |
| C10 | 5.0 μF |
| R1 | 15 Ω |
| L1, L2 | 3/16" x 1" Copper Strap |
| L3 | 1.5 μH |
| L4 | 10 μH |
| L5 | 1 Turn #16 AWG, 5/16" I.D. |

## BROADBAND DATA (Circuit, Figure 6)

FIGURE 2 – POWER GAIN versus FREQUENCY

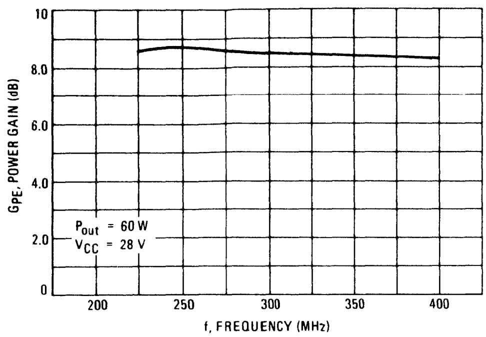



FIGURE 3 – EFFICIENCY versus FREQUENCY

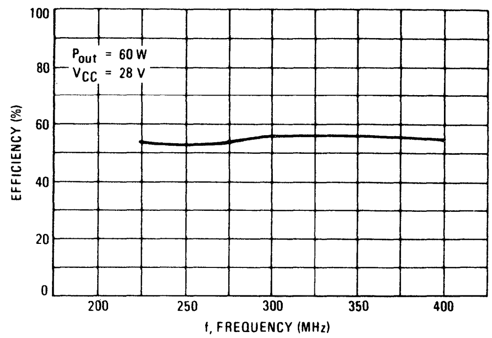



FIGURE 4 – INPUT VSWR versus FREQUENCY

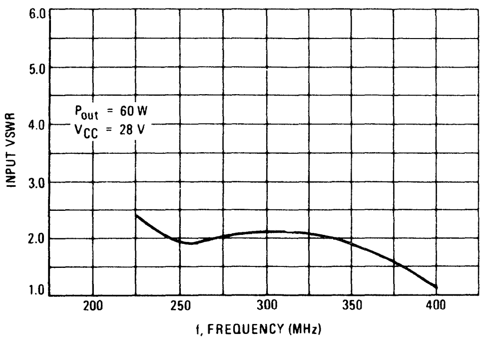
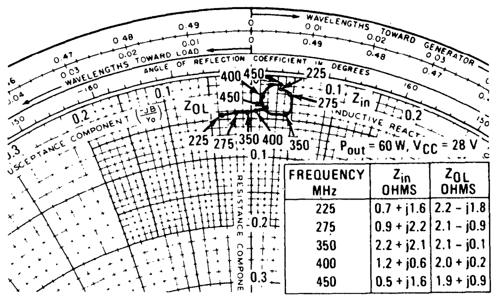
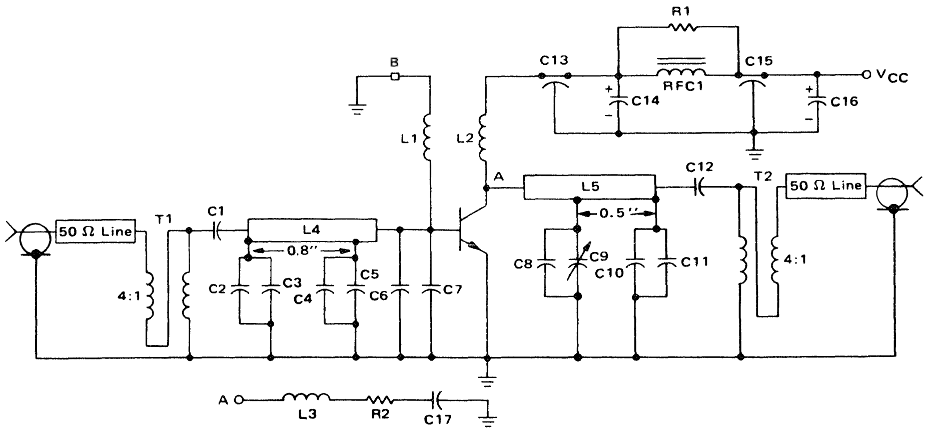



FIGURE 5 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| FREQUENCY MHz | $Z_{in}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 225 | 0.7 + j1.6 | 2.2 – j1.8 |
| 275 | 0.9 + j2.2 | 2.1 – j0.9 |
| 350 | 2.2 + j2.1 | 2.1 – j0.1 |
| 400 | 1.2 + j0.6 | 2.0 + j0.2 |
| 450 | 0.5 + j1.6 | 1.9 + j0.9 |

FIGURE 6 – 225–400 MHz BROADBAND TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1 | 68 pF | RFC1 | Ferrite Bead Choke, Ferroxcube VK200 19/4B |
| C2, C4, C8, C10 | 27 pF | B | Ferroxcube 56-590-65/4B Ferrite Bead |
| C3, C5, C11 | 10 pF | T1, T2 | 25 Ohms (UT25) Miniature Coaxial Cable, 1 turn |
| C6, C7 | 51 pF | R1 | 11 Ω, 1 W |
| C9 | 1–10 pF JOHANSON | R2 | 20 Ω, 1/4 W |
| C12 | 100 pF | L1 | 10 Turns, #22 AWG, 1/8" I.D. |
| C13, C15 | 680 pF | L2 | 4 Turns, #16 AWG, 1/4" I.D. |
| C14, C16 | 1.0 μF, 35 V Tantalum | L3 | 6 Turns, #24 AWG, 1/8" I.D. |
| C17 | 0.1 μF, ERIE Red Cap | L4, L5 | 1" x 0.25" Microstrip Line |

Board Material 0.031" Thick Teflon-Fiberglass

## NARROW BAND DATA

FIGURE 7 – $P_{out}$ versus FREQUENCY

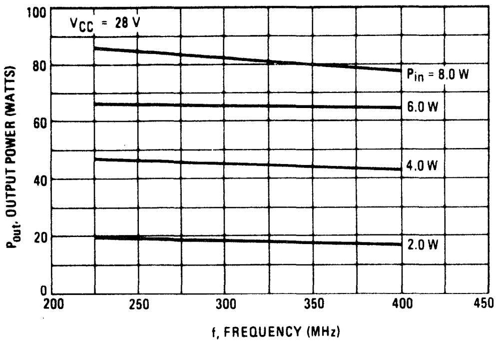



FIGURE 8 – OUTPUT POWER versus INPUT POWER

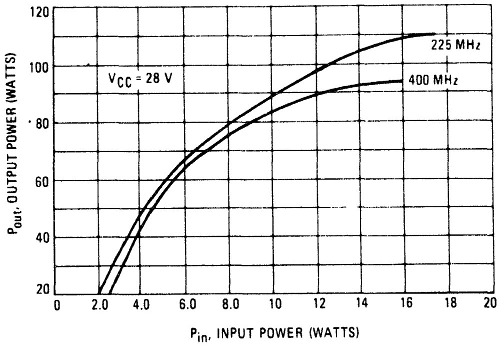



FIGURE 9 – POWER-GAIN versus FREQUENCY

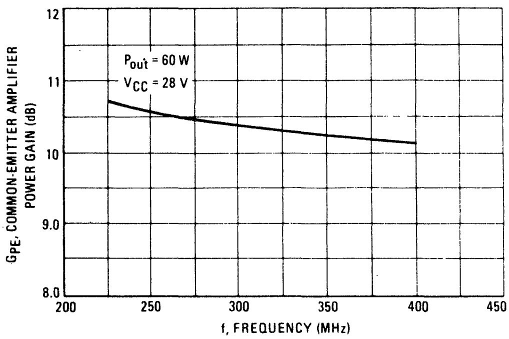



FIGURE 10 – OUTPUT POWER versus SUPPLY VOLTAGE

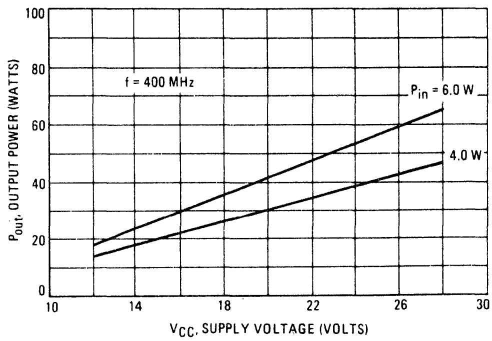
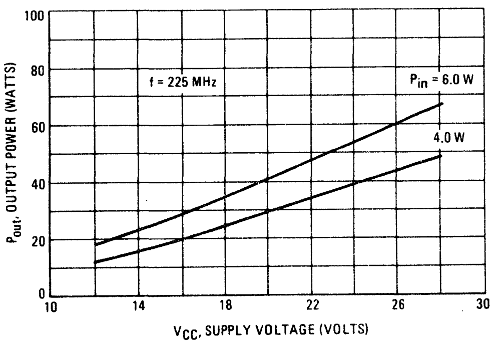



FIGURE 11 – OUTPUT POWER versus SUPPLY VOLTAGE



MOTOROLA Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF313
# MRF313A

## The RF Line

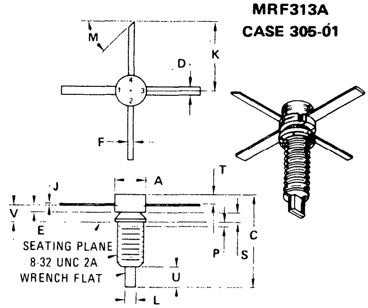
### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for wide band amplifier, driver or oscillator applications in military, mobile, and aircraft radio.

- Specified 28 Volt, 400 MHz Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 15 dB
  Efficiency = 45%.
- Emitter Ballast and Low Current Density for Improved MTBF
- Common Emitter for Improved Stability

1.0 W – 400 MHz
HIGH FREQUENCY TRANSISTOR
NPN SILICON

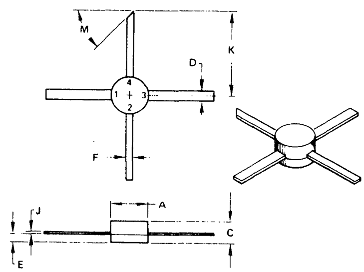
MRF313A
CASE 305-01




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 13.97 | 16.26 | 0.550 | 0.640 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| L | 1.40 | 1.65 | 0.055 | 0.065 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 1.40 | 1.65 | 0.055 | 0.065 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.79 | 3.81 | 0.110 | 0.150 |
| V | 2.41 | 2.92 | 0.095 | 0.115 |

MRF313
CASE 305A-01




STYLE 1
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 2.41 | 3.30 | 0.095 | 0.130 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector – Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector – Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter – Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 150 | mAdc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate above 25°C | $P_D$ | 2.5<br>35 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

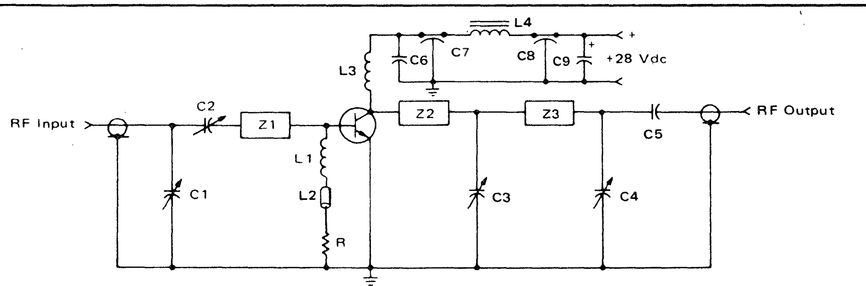
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 28.5 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 35 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 20 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 Adc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | 60 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 100 mAdc, $V_{CE}$ = 20 Vdc, f = 200 MHz) | $f_T$ | – | 2.5 | – | GHz |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.5 | 5.0 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain(1) ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $G_{pe}$ | 15 | 16 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $\eta$ | – | 45 | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $Z_{in}$ | – | 6.4-j4.8 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 28 Vdc, $P_{out}$ = 1.0 W, f = 400 MHz) | $Z_{out}$ | – | 75-j45 | – | Ohms |

(1) Class C

FIGURE 1 – 400 MHz POWER GAIN TEST CIRCUIT




C1,C2,C4 1.0-20 pF JOHANSON 9063
C3 1.0-10 pF JOHANSON
C5 150 pF Chip
C6 0.1 µF
C7,C8 680 pF Feedthru
C9 1.0 µF TANTALUM

L1,L3 5 Turns, AWG #20, ¼″ I.D.
L2 Ferrite Bead, FERROXCUBE No. 56-590-65/4B
L4 FERROXCUBE VK200-20/4B
Input/Output Connectors — Type N
Board – Glass Teflon, ε = 2.56, t = 0.062″

R 4.7 Ohms, ¼ W
Z1 2.0″ x 0.1″ MICROSTRIP LINE
Z2,Z3 2.6″ x 0.1″ MICROSTRIP LINE

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

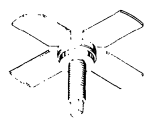
# MRF321

## The RF Line

**10 W – 400 MHz**

**RF POWER TRANSISTOR**

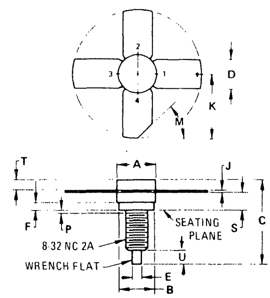
**NPN SILICON**



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal driver and predriver amplifier stages in the 200–500 MHz frequency range.

- Guaranteed Performance at 400 MHz and 28 Vdc
  Output Power = 10 Watts
  Minimum Gain = 12 dB
  Efficiency = 50%
- 100% Tested for Load Mismatch at All Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability
- Computer-Controlled Wirebonding Gives Consistent Input Impedance




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.51 | 0.590 | 0.650 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.40 | 1.65 | 0.055 | 0.065 |
| F | 1.52 | – | 0.060 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |

CASE 244-04

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak | $I_C$ | 1.1<br>1.5 | Adc |
| Total Device Dissipation @ $T_A$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 27<br>160 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

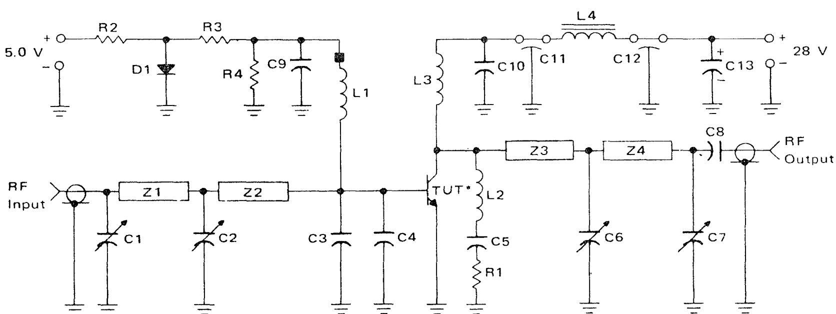
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 6.4 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 20 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 500 mA, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 10 | 12 | pF |
| **FUNCTIONAL TESTS (FIGURE 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 10 W, f = 400 MHz) | $G_{PE}$ | 12 | 13 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 10 W, f = 400 MHz) | $\eta$ | 50 | 60 | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 10, f = 400 MHz, VSWR = 30:1 all phase angles) | $\psi$ | No Degradation in Output Power | | | |

FIGURE 1 – 400 MHz TEST CIRCUIT




C1, C2, C3 – 1.0–20 pF Johanson Trimmer (JMC 5501)
C3, C4 – 47 pF ATC Chip Capacitor
C5, C10 – 0.1 μF Erie Redcap
C7 – 0.5–10 pF Johanson Trimmer (JMC 5201)
C8 – 0.018 μF Vitramon Chip Capacitor
C9 – 200 pF UNELCO Capacitor
C11, C12 – 680 pF Feedthru
C13 – 1 μF, 50 Volt Tantalum Capacitor

R1 – 5.1 Ω, 1/4 Watt
R2 – 120 Ω, 1 Watt
R3 – 20 Ω, 1/2 Watt
R4 – 47 Ω, 1/2 Watt

L1 – 0.33 μH Molded Choke with Ferroxcube Bead (Ferroxcube 56-590-65/4B) on Ground End of Coil
L2 – 4 Turns #20 Enamel, 1/8″ ID
L3 – 6 Turns #20 Enamel, 1/4″ ID
L4 – Ferroxcube VK200-19/4B

Z1 – Microstrip 0.1″ W x 1.35″ L
Z2 – Microstrip 0.1″ W x 0.55″ L
Z3 – Microstrip 0.1″ W x 0.8″ L
Z4 – Microstrip 0.1″ W x 1.75″ L

D1 – 1N4001

Board – Glass Teflon, $\epsilon_R$ = 2.56, t = 0.062″

Input/Output Connectors – Type N

*Transistor Under Test

FIGURE 2 – OUTPUT POWER versus FREQUENCY

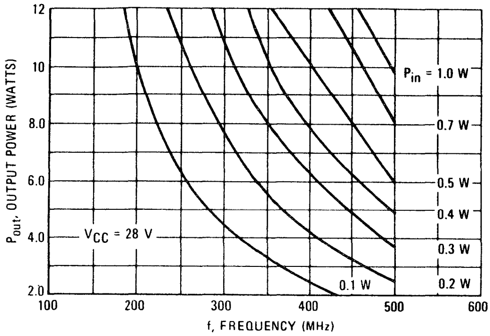



FIGURE 3 – OUTPUT POWER versus INPUT POWER

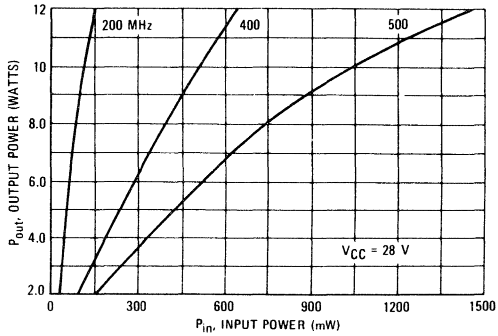



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

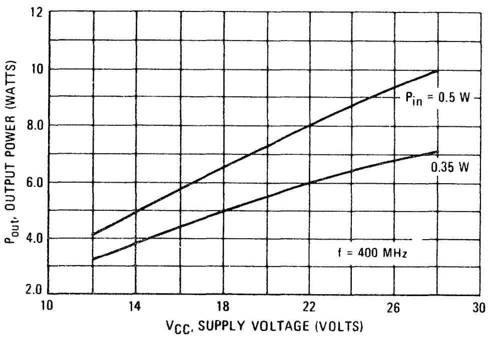



FIGURE 5 – POWER GAIN versus FREQUENCY

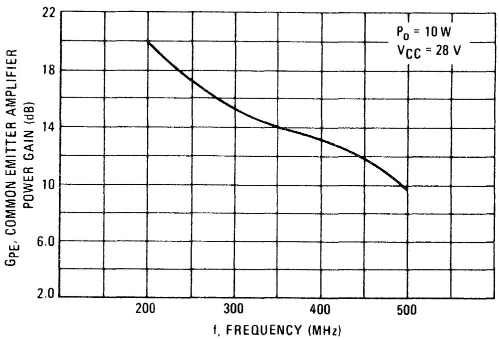
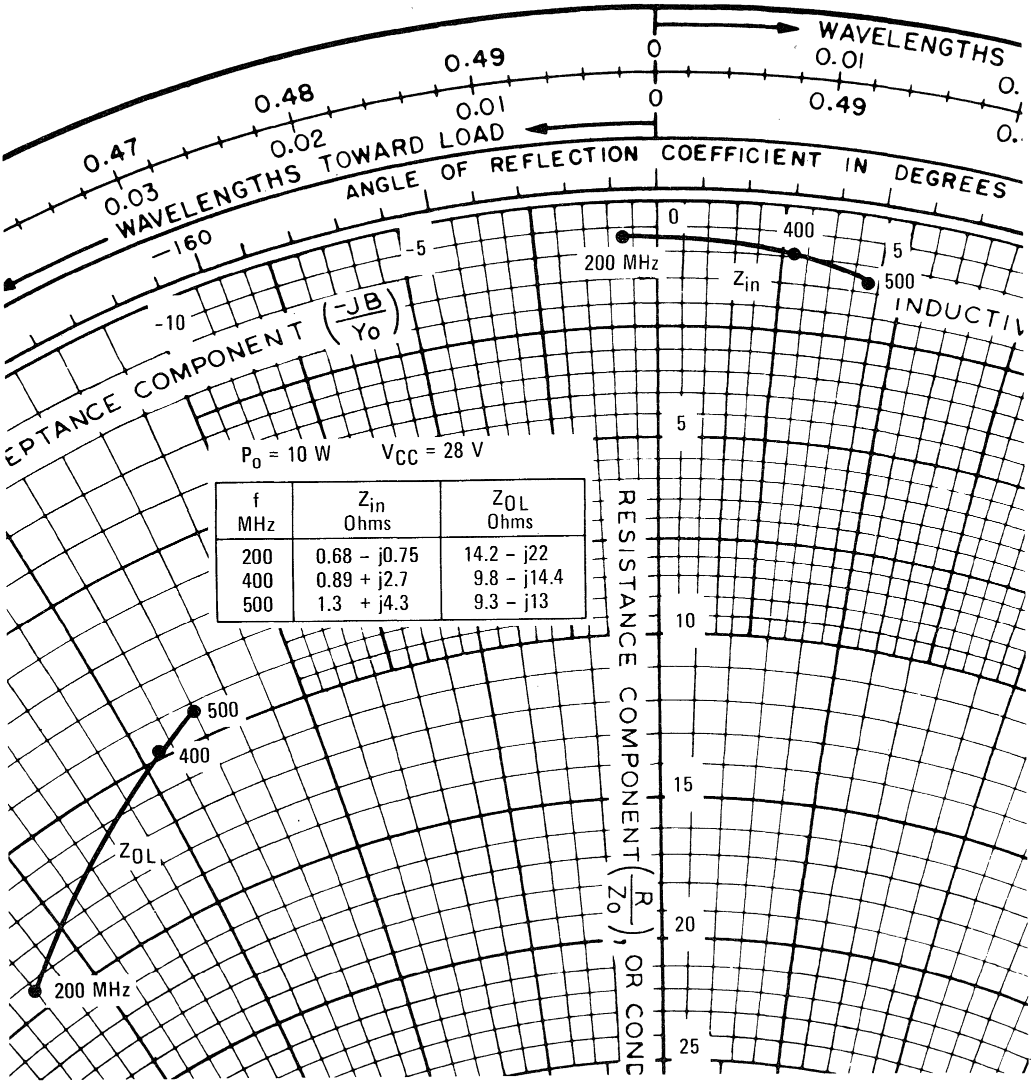


FIGURE 6 – SERIES EQUIVALENT IMPEDANCE




| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 200 | 0.68 – j0.75 | 14.2 – j22 |
| 400 | 0.89 + j2.7 | 9.8 – j14.4 |
| 500 | 1.3 + j4.3 | 9.3 – j13 |

MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

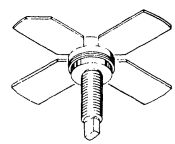
# MRF323

## The RF Line

20 W – 400 MHz

RF POWER
TRANSISTOR

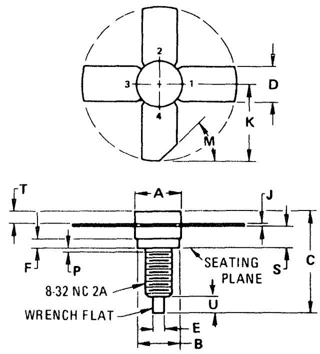
NPN SILICON



## NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal driver and predriver amplifier stages in the 200-500 MHz frequency range.

- Guaranteed Performance at 400 MHz and 28 V
  Output Power = 20 Watts
  Minimum Gain = 10 dB
  Efficiency = 50%
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability
- Computer-Controlled Wirebonding Gives Consistent Input Impedance




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.51 | 0.590 | 0.650 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.40 | 1.65 | 0.055 | 0.065 |
| F | 1.52 | – | 0.060 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |

CASE 244-04

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous<br>— Peak | $I_C$ | 2.2<br>3.0 | Adc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 55<br>310 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

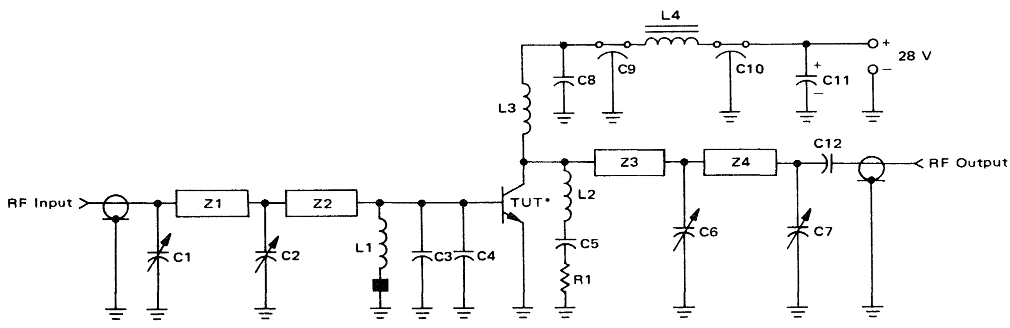
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 3.2 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 20 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 2.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 2.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 20 | 24 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 20 W, f = 400 MHz) | $G_{PE}$ | 10 | 11 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 20 W, f = 400 MHz) | $\eta$ | 50 | 60 | – | % |
| Load Mismatch ($V_{CC}$ = 28 V, $P_{out}$ = 20 W, f = 400 MHz, VSWR = 30:1 all phase angles) | $\psi$ | No Degradation in Output Power | | | |

**FIGURE 1 – 400 MHz TEST CIRCUIT**




C1, C2, C6 – 1.0-20 pF Johanson Trimmer (JMC 5501)
C3, C4 – 47 pF ATC Chip Capacitor
C5, C8 – 0.1 μF Erie Redcap
C7 – 0.5-10 pF Johanson Trimmer (JMC 5201)
C9, C10 – 680 pF Feedthru
C11 – 1.0 μF 50 Volt Tantalum
C12 – 0.018 μF Vitramon Chip Capacitor
R1 – 5.1 Ω 1/4 Watt
L1 – 0.33 μH Molded Choke with Ferroxcube Bead (Ferroxcube 56-590-65/4B) on Ground End

L2 – 6 Turns #20 Enamel, ¼" ID, Closewound
L3 – 4 Turns #20 Enamel, 1/8" ID, Closewound
L4 – Ferroxcube VK200 – 19/4B
Z1 – Microstrip 0.1" W x 1.35" L
Z2 – Microstrip 0.1" W x 0.55" L
Z3 – Microstrip 0.1" W x 0.8" L
Z4 – Microstrip 0.1" W x 1.75" L
Board – Glass Teflon $\epsilon_R$ = 2.56 t = 0.062"
Input/Output Connectors – Type N
*Transistor Under Test

FIGURE 2 – OUTPUT POWER versus FREQUENCY

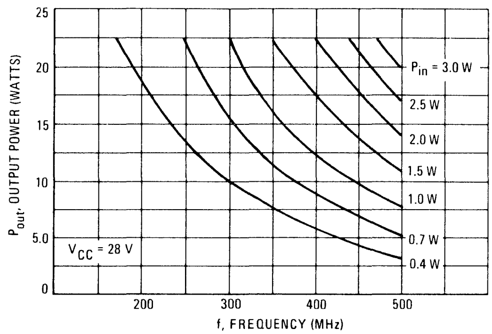



FIGURE 3 – OUTPUT POWER versus INPUT POWER

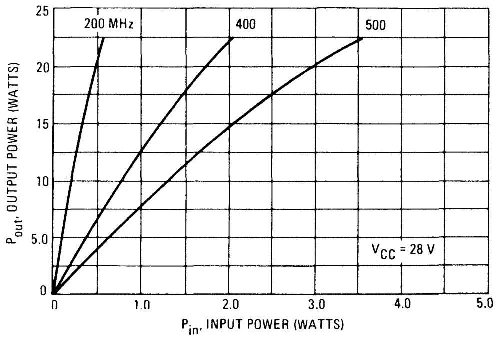



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

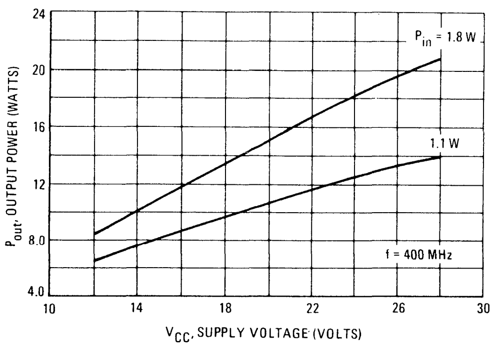



FIGURE 5 – POWER GAIN versus FREQUENCY

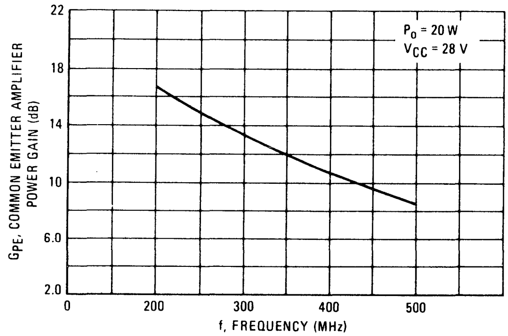
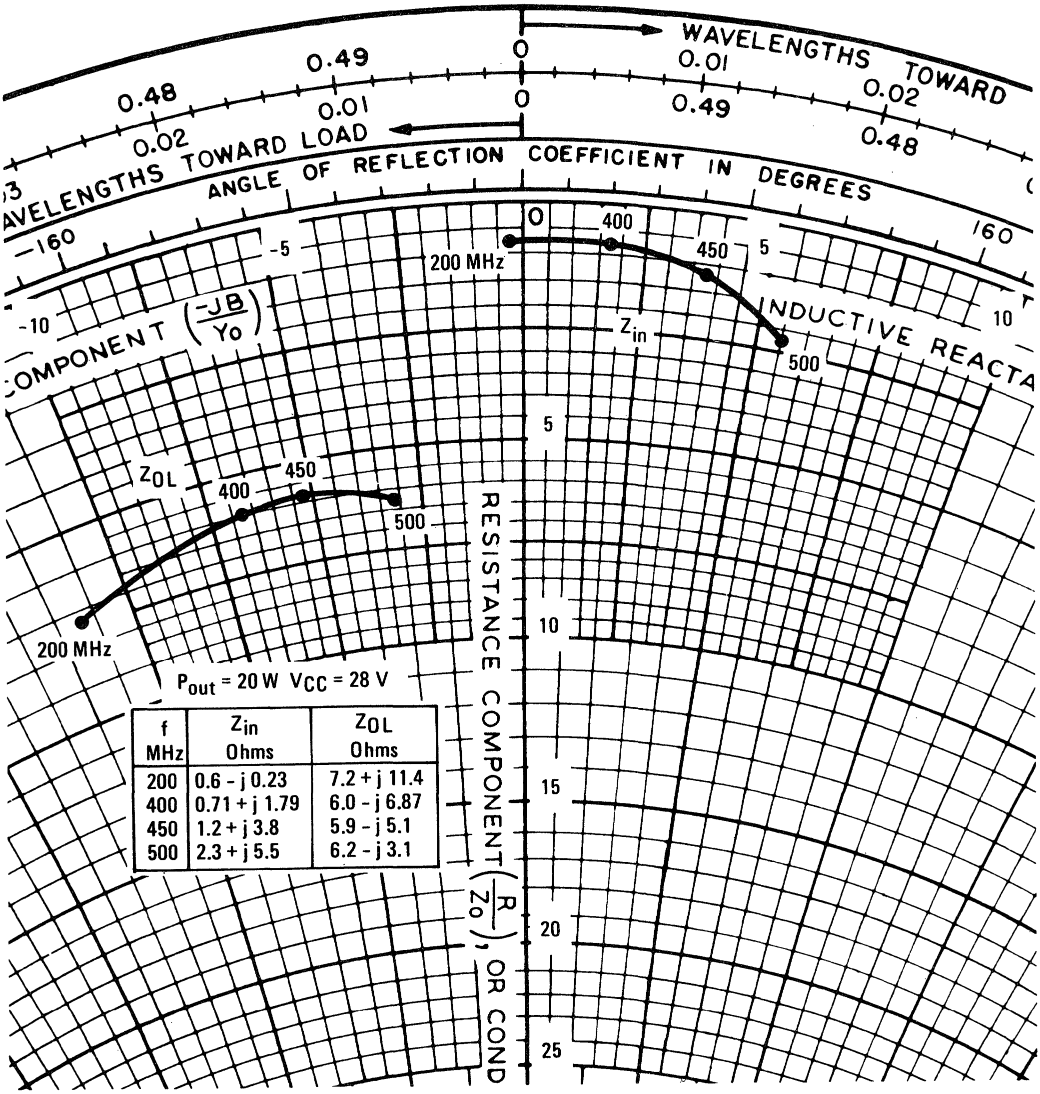


FIGURE 6 – SERIES EQUIVALENT IMPEDANCE




| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 200 | 0.6 - j 0.23 | 7.2 + j 11.4 |
| 400 | 0.71 + j 1.79 | 6.0 - j 6.87 |
| 450 | 1.2 + j 3.8 | 5.9 - j 5.1 |
| 500 | 2.3 + j 5.5 | 6.2 - j 3.1 |

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# MRF325

## The RF Line

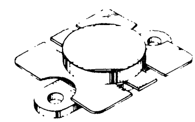
### NPN SILICON RF POWER TRANSISTOR

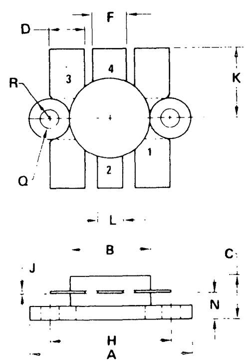
. . . designed primarily for wideband large-signal output and driver amplifier stages in the 100-500 MHz frequency range.

- Specified 28 Volt, 400 MHz Characteristics –
  Output Power = 30 Watts
  Minimum Gain = 8.5 dB
  Efficiency = 54% (Min)
- Built-In Matching Network for Broadband Operation Using Internal Matching Techniques
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization for High Reliability Applications

**30 W – 225-400 MHz CONTROLLED "Q" BROADBAND RF POWER TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | - | 0.405 | - |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak | $I_C$ | 3.4<br>4.5 | Adc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 82<br>0.47 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

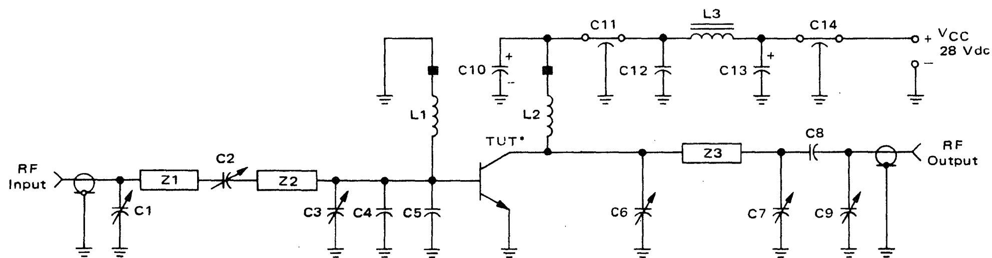
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.13 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 30 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 30 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 3.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 30 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 60 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 3.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.5 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 30 | 40 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 400 MHz) | $G_{PE}$ | 8.5 | 9.5 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 400 MHz) | $\eta$ | 50 | 60 | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 30 W, f = 400 MHz, VSWR = 30:1 all angles) | $\psi$ | No Degradation in Output Power | | | |

**FIGURE 1 – 400 MHz TEST CIRCUIT**




C1, C9 – 1.0–10 pF Johanson Capacitor (JMC 5201)
C2, C3, C6, C7 – 1.0–20 pF Johanson Capacitor (JMC 5501)
C4, C5 – 36 pF ATC 100-mil Chip Capacitor
C8 – 100 pF UNELCO
C10, C13 – 1.0 µF 50 V Tantalum
C11, C14 – 680 pF Feedthru
C12 – 0.1 µF Erie Redcap
L1 – 8 Turns #26 AWG Enameled, 1/16" ID Closewound with Ferroxcube Bead (#56-590-65/4B) on Ground End
L2 – 14 Turns, #22 AWG Enameled, Closewound on a 470 Ω, 2 Watt Resistor with Ferroxcube Bead (#56-590-65/4B) on Cold End of L2
L3 – Ferroxcube VK200-19/4B Ferrite Choke
Z1 – Microstrip 0.19" W x 0.88" L
Z2 – Microstrip 0.28" W x 1.0" L
Z3 – Microstrip 0.31" W x 1.25" L
Board – Glass Teflon $\epsilon_R$ = 2.56, t = 0.062"
Input/Output Connectors – Type N

TUT Socket Lead Frame Etched from 80-mil-Thick Copper
*Transistor Under Test

FIGURE 2 – OUTPUT POWER versus INPUT POWER

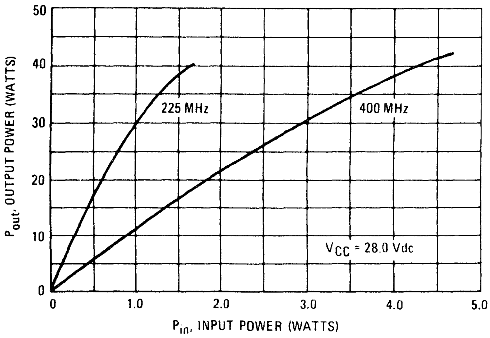



FIGURE 3 – OUTPUT POWER versus SUPPLY VOLTAGE – 225 MHz

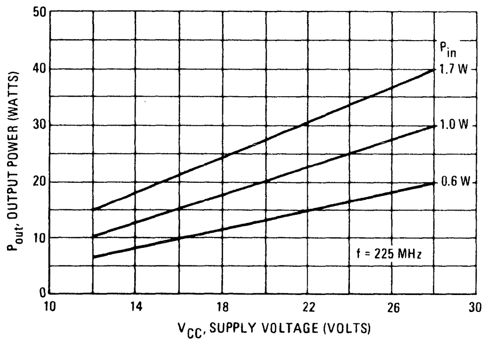



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE – 400 MHz

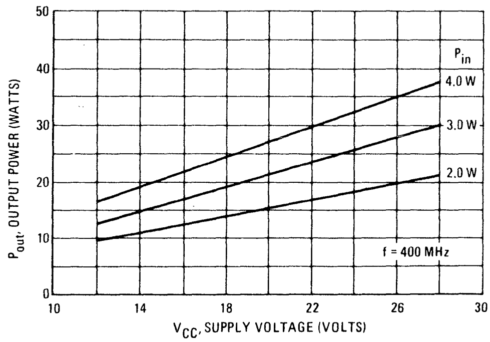
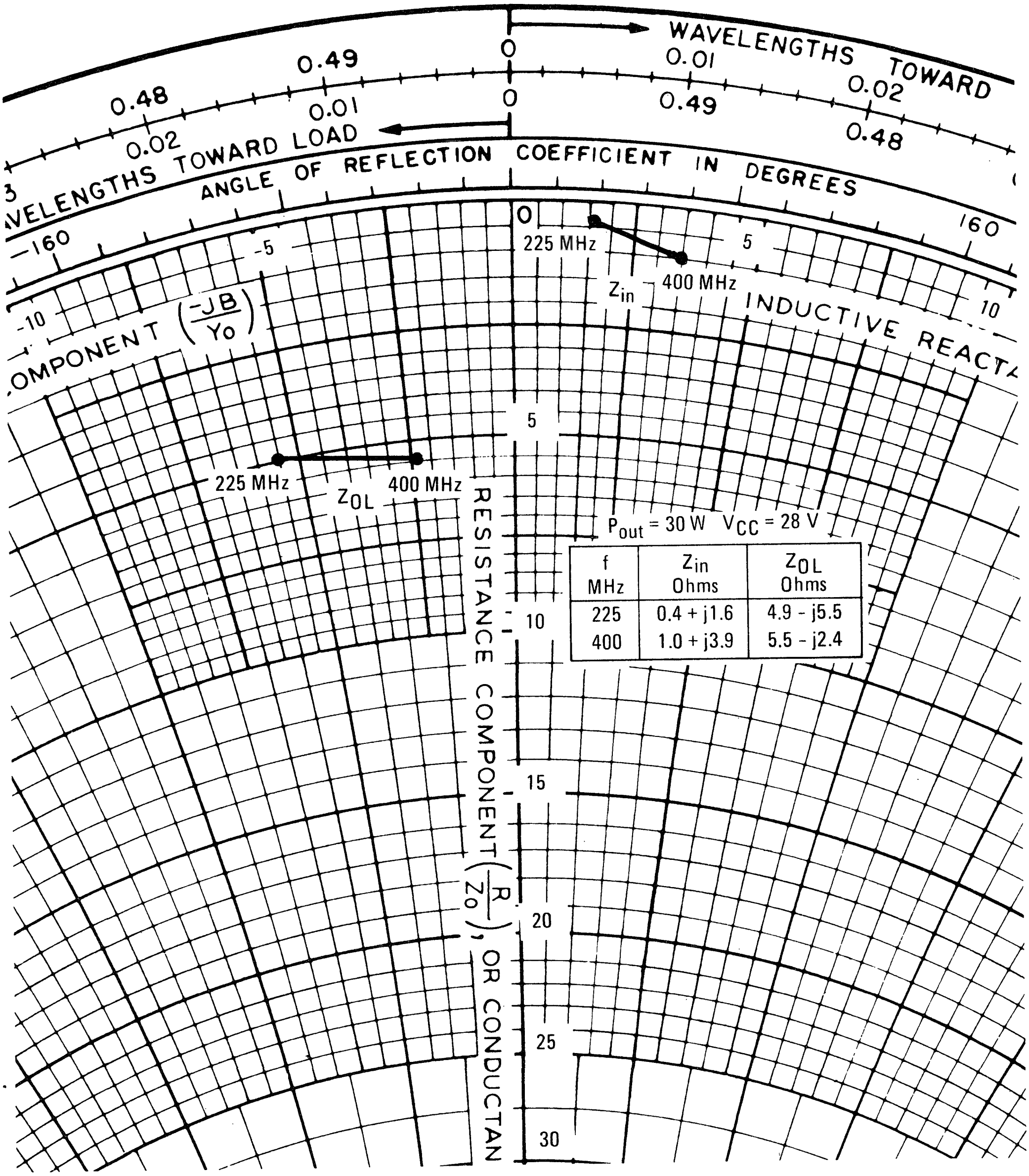


FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 225 | 0.4 + j1.6 | 4.9 - j5.5 |
| 400 | 1.0 + j3.9 | 5.5 - j2.4 |

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# MRF326

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal output amplifier stages in the 100-500 MHz frequency range.

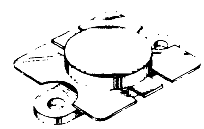
- Guaranteed Performance @ 400 MHz, 28 Vdc

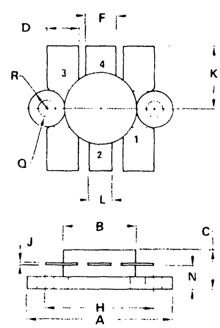
  Output Power = 40 Watts
  Minimum Gain = 9.0 dB
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability Applications

40 W – 225–400 MHz

**CONTROLLED "Q" BROADBAND RF POWER TRANSISTOR**

**NPN SILICON**






STYLE 1
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

**CASE 316-01**

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous<br>Peak | $I_C$ | 4.5<br>6.0 | Adc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$ (1)<br>Derate above $25^{\circ}C$ | $P_D$ | 110<br>0.63 | Watts<br>$W/^{\circ}C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^{\circ}C$ |

### THERMAL CHARACTERISTICS

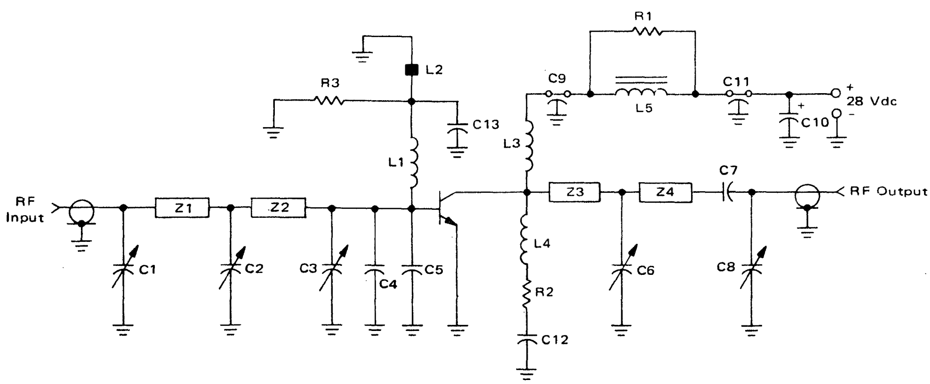
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.6 | $^{\circ}C/W$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 40 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 40 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 4.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 40 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 60 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 4.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 50 | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 45 | 60 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 40 W, f = 400 MHz, $I_C$ Max = 2.85 Adc) | $G_{PE}$ | 9.0 | 11 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 40 W, f = 400 MHz, $I_C$ Max = 2.85 Adc) | $\eta$ | 50 | – | – | % |
| Load Mismatch ($V_{CC}$ = 28 Vdc, $P_{out}$ = 40 W CW, f = 400 MHz, VSWR = 30:1 all phase angles) | $\psi$ | No Degradation in Power Output | | | |

**FIGURE 1 – 400 MHz TEST AMPLIFIER**




C1 – 1.0-10 pF Johanson, Capacitor (JMC 5201)
C2, C3, C6, C8 – 1.0-20 pF Johanson Capacitor
C4, C5 – 36 pF ATC "B" Style Chip Capacitor
C7, C9, C13 – 100 pF UNELCO Capacitor
C11 – 680 pF Feedthru
C10 – 1.0 µF 50 V Tantalum
C12 – 0.1 µF Erie Redcap
L1 – 8 Turns #26 AWG Enameled, 1/16" ID Closewound
L2, L5 – Ferroxcube VK200-19/4B Ferrite Choke

L3 – 8 Turns #20 AWG Enameled, 1/4" ID Closewound
L4 – 4 Turns #26 AWG 0.1" ID
R1 – 10 Ohm 2.0 W Carbon
R2, R3 – 10 Ohm 1.0 W Carbon
Z1 – Microstrip 0.19" W x 1.28" L
Z2 – Microstrip 0.28" W x 1.0" L
Z3 – Microstrip 0.31" W x 1.0" L
Z4 – Microstrip 0.31" W x 0.9" L
Board – Glass Teflon $\epsilon_R$ = 2.56 t = 0.062"
Input/Output Connectors – Type N UG58 A/U

FIGURE 2 — OUTPUT POWER versus INPUT POWER

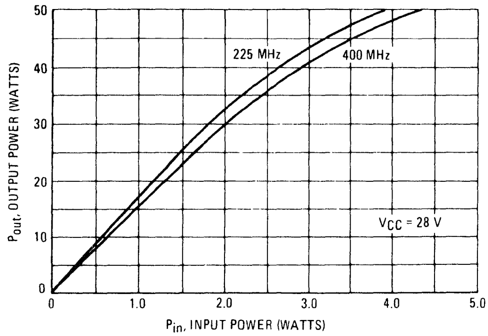



FIGURE 3 — OUTPUT POWER versus SUPPLY VOLTAGE
f = 225 MHz

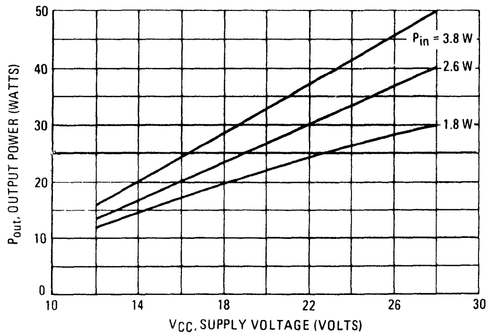



FIGURE 4 — OUTPUT POWER versus SUPPLY VOLTAGE
f = 400 MHz

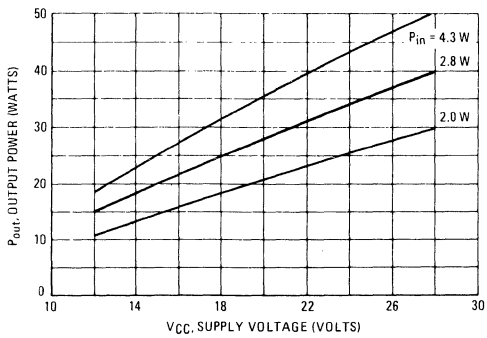
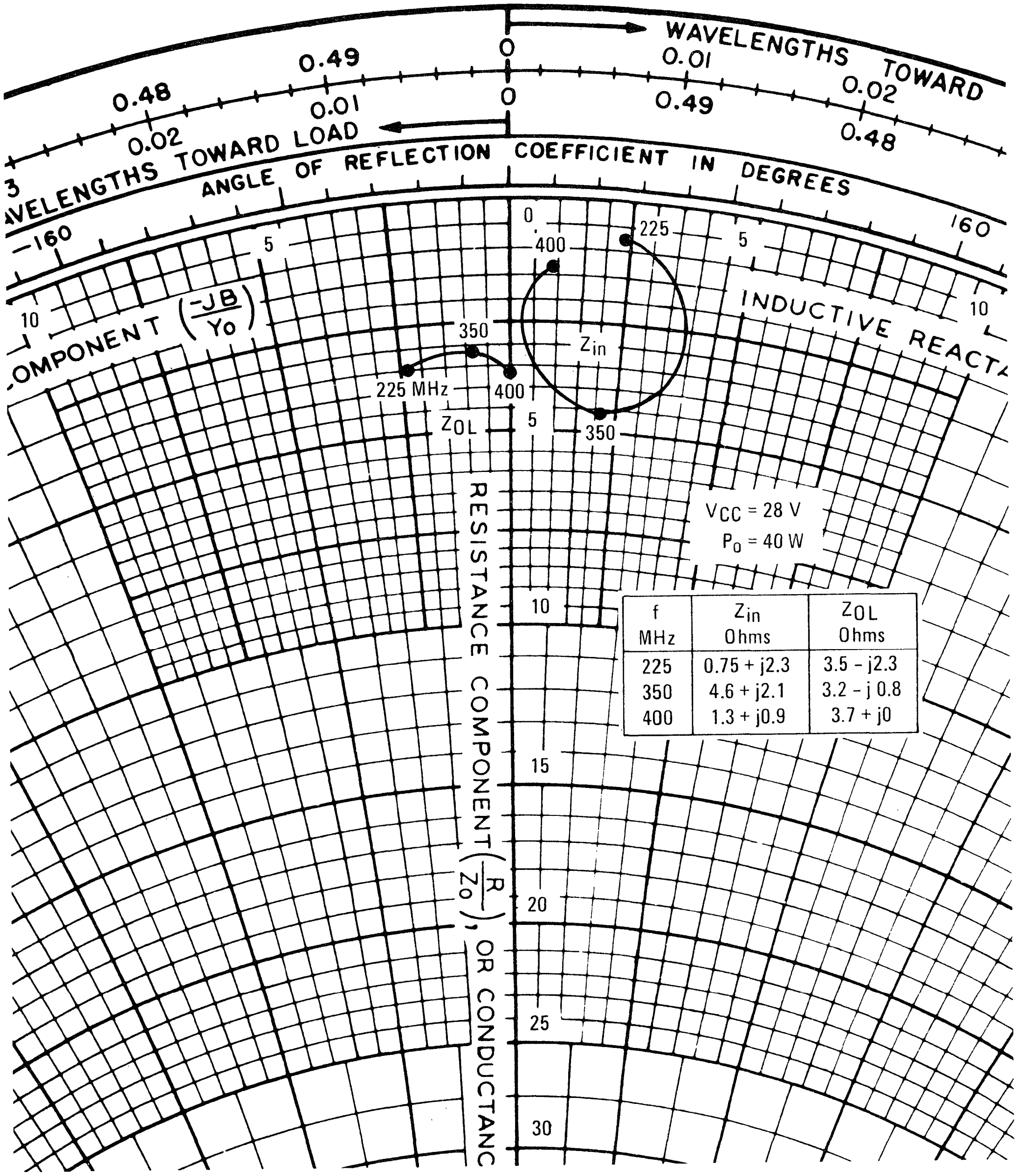


FIGURE 5 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| f MHz | Zin Ohms | ZOL Ohms |
|---|---|---|
| 225 | 0.75 + j2.3 | 3.5 – j2.3 |
| 350 | 4.6 + j2.1 | 3.2 – j 0.8 |
| 400 | 1.3 + j0.9 | 3.7 + j0 |

# MOTOROLA Semiconductors

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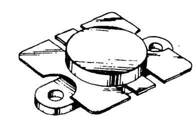
# MRF327

## The RF Line

80 W – 100-500 MHz

CONTROLLED "Q"
BROADBAND RF POWER
TRANSISTOR

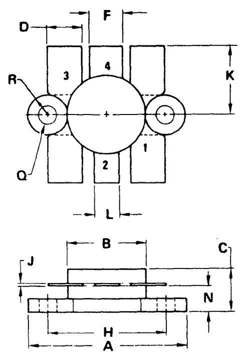
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal output amplifier stages in the 100-500 MHz frequency range.

- Guaranteed Performance @ 400 MHz, 28 Vdc
  Output Power = 80 Watts over 225–400 MHz Band
  Minimum Gain = 7.3 dB @ 400 MHz
- Built-in Matching Network for Broadband Operation Using Double Match Technique
- 100% Tested for Load Mismatch at all Phase Angles with 30:1 VSWR
- Gold Metallization System for High Reliability Applications
- Characterized for 100–500 MHz




STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak | $I_C$ | 9.0<br>12.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 250<br>1.43 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

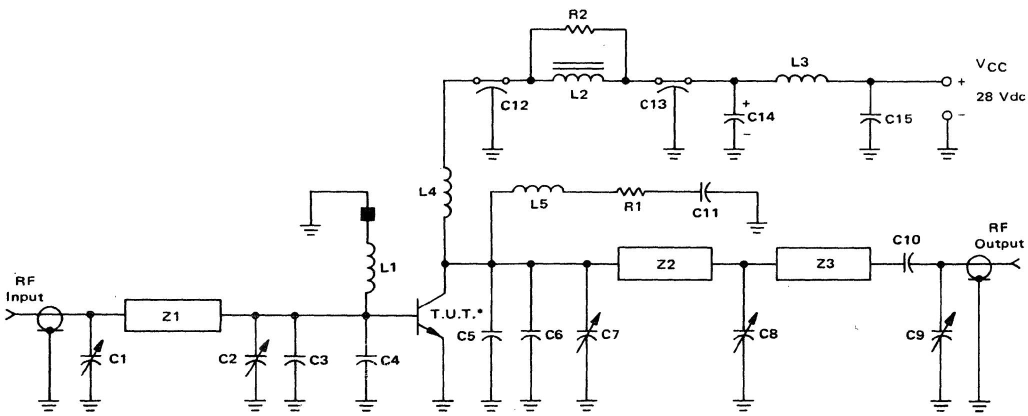
| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.7 | $^oC/W$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 80 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 80 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 8.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 80 mAdc, $I_C$ = 0) | $BV_{CBO}$ | 60 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 4.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | 80 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 28 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 100 | 145 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 80 W, f = 400 MHz) | $G_{PE}$ | 7.3 | 9.0 | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 80 W, f = 400 MHz) | $\eta$ | 50 | 60 | – | % |
| Load Mismatch ($V_{CC}$ = 28 V, $P_{out}$ = 80 W, f = 400 MHz, VSWR 30:1 all phase angles) | $\psi$ | No Degradation in Output Power | | | |

FIGURE 1 – 400 MHz TEST CIRCUIT




C1, C2, C7, C8, C9 – 1.0-20 pF Piston Trimmer (Johanson JMC 5501)
C3, C4 – 36 pF ATC 100 mil Chip Capacitor
C5, C6 – 43 pF ATC 100-mil Chip Capacitor
C10 – 100 pF UNELCO
C11, C15 – 0.1 µF Erie Redcap
C12, C13 – 680 pF Feedthru
C14 – 1.0 µF 50 V Tantalum
L1 – 4 Turns #22 AWG Enameled, 3/16" ID Closewound with Ferroxcube Bead (#56-590-65/4B) on Ground End of Coil
L2 – Ferroxcube VK200-19/4B Ferrite Choke
L3 – 7 Turns #18 AWG, 11/16" Long, Wound on a 100 kΩ 2 Watt Resistor
L4 – 6 Turns #20 AWG Enameled, 3/16" ID Closewound
L5 – 4 Turns #22 AWG Enameled, 1/8" ID Closewound
Z1 – Microstrip 0.2" W x 1.5" L
Z2 – Microstrip 0.17" W x 1.16" L
Z3 – Microstrip 0.17" W x 0.63" L
R1, R2 – 10 Ω 2 Watt
Board – Glass Teflon $\epsilon_R$ = 2.56, t = 0.062"
Input/Output Connectors Type N
T.U.T. Socket Lead Frame Etched from 80 mil Thick Copper
*Transistor Under Test

FIGURE 2 – POWER GAIN versus FREQUENCY

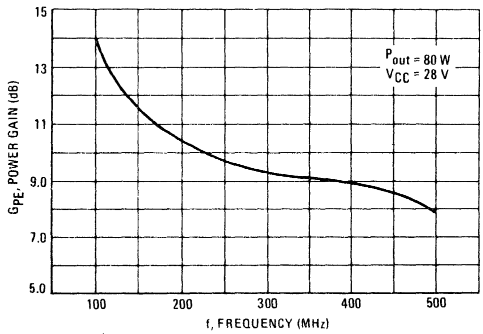



FIGURE 3 – OUTPUT POWER versus FREQUENCY

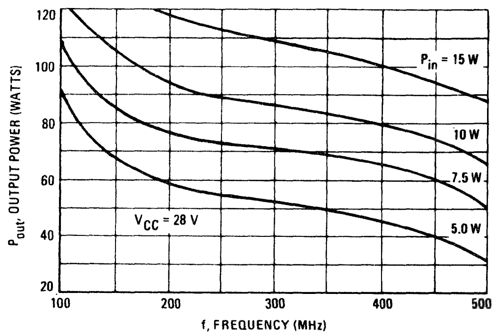



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE
f = 225 MHz

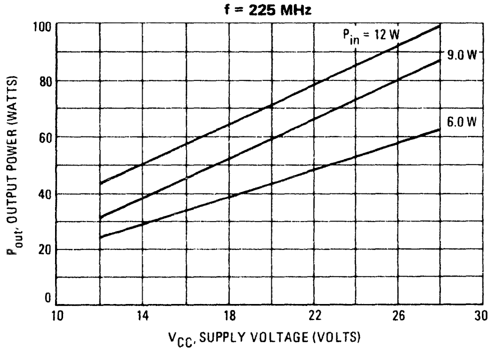



FIGURE 5 – OUTPUT POWER versus SUPPLY VOLTAGE
f = 400 MHz

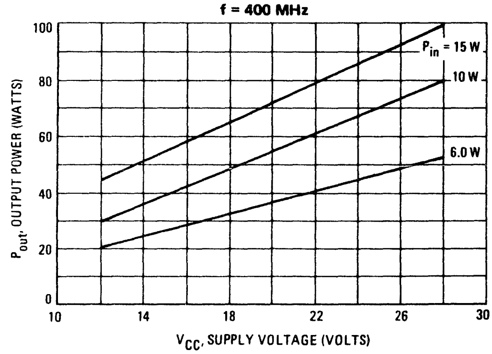



FIGURE 6 – OUTPUT POWER versus INPUT POWER

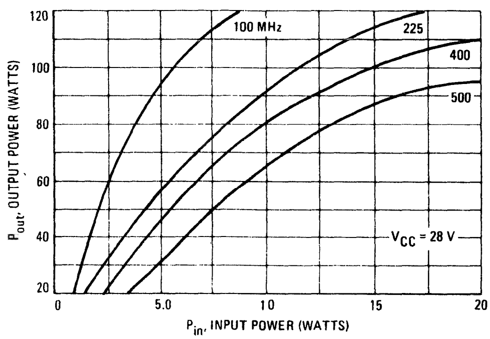
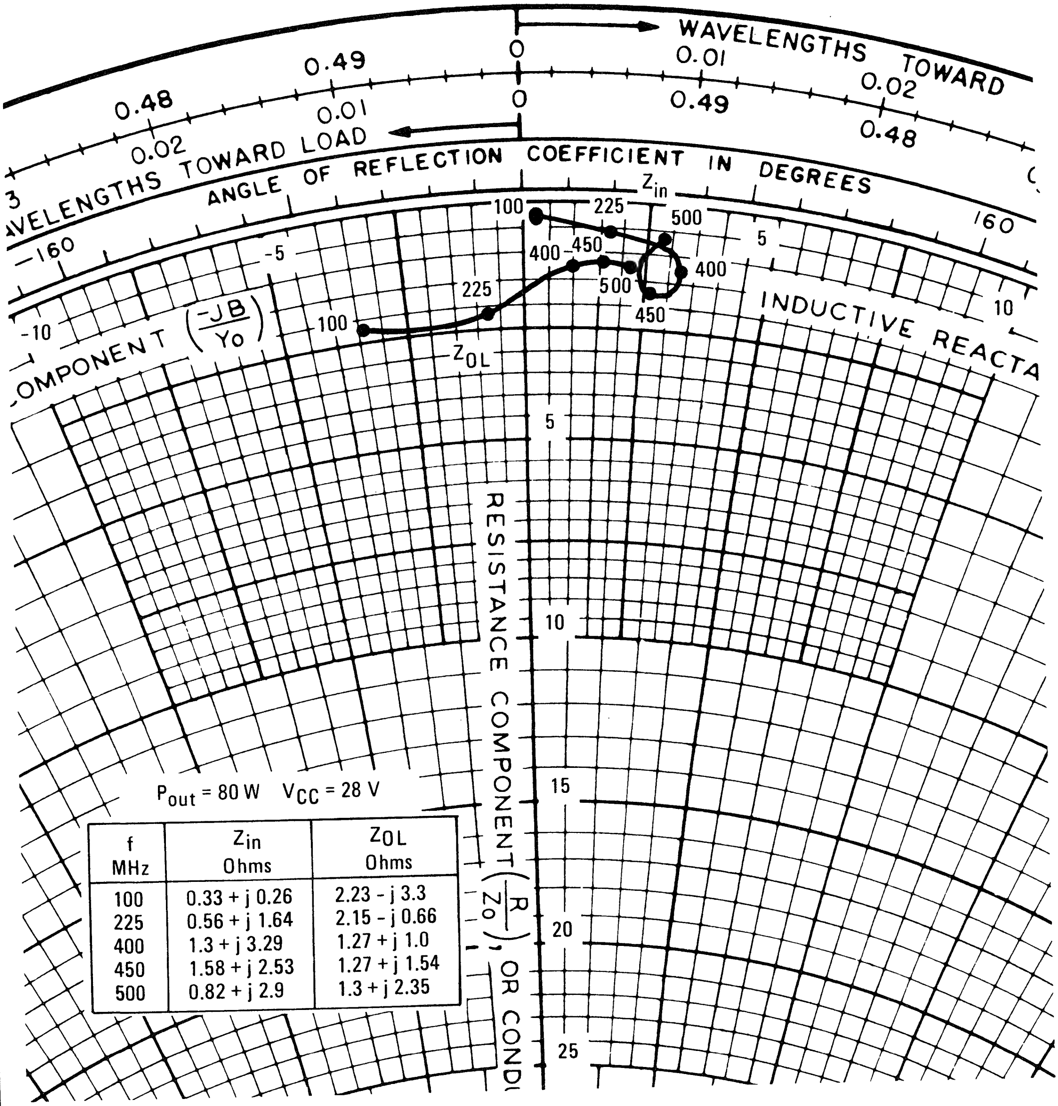


FIGURE 7 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 100 | 0.33 + j 0.26 | 2.23 - j 3.3 |
| 225 | 0.56 + j 1.64 | 2.15 - j 0.66 |
| 400 | 1.3 + j 3.29 | 1.27 + j 1.0 |
| 450 | 1.58 + j 2.53 | 1.27 + j 1.54 |
| 500 | 0.82 + j 2.9 | 1.3 + j 2.35 |

# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF509

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

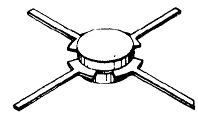
. . . designed for amplifier, frequency multiplier, or oscillator applications in military and industrial equipment. Suitable for use as output, driver or predriver stages in VHF and UHF applications.

- 2N3866 – Packaged for Stripline Designs
- High Power Gain @ 400 MHz
  $G_{PE}$ = 10 dB @ $V_{CC}$ = 28 Vdc

**1 W – 400 MHz**

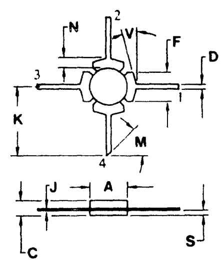
**RF POWER TRANSISTOR**

**NPN SILICON**



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 55 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.4 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate Above 25°C | $P_D$ | 2.0<br>11.4 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to 150 | °C |



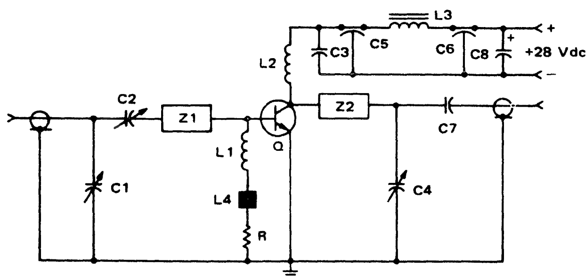

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| C | 2.84 | 3.45 | 0.112 | 0.136 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| F | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| M | 45° NOM | | 45° NOM | |
| N | 1.40 | 1.65 | 0.055 | 0.065 |
| S | 1.40 | 1.65 | 0.055 | 0.065 |
| V | 10° | 20° | 10° | 20° |

STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

NOTES:
1. DIM "N" IS FROM DIA "A" TO ANGLE "V".

CASE 323-01

**FIGURE 1 – 400 MHz POWER GAIN TEST CIRCUIT**




| | | | |
|---|---|---|---|
| C1, C2, C4 | 1.0-20 pF (Johanson 9063) | Z1 | 2.0" x 0.1" Strip |
| C3 | 0.1 μF | Z2 | 5.3" x 0.1" Strip |
| C5, C6 | 680 pF Feedthru | L1, L2 | 5 T AWG #20, 1/4" I.D. |
| C7 | 150 pF Chip | L3 | Ferroxcube VK200 |
| C8 | 1.0 μF Tantalum | L4 | Ferroxcube Bead 5L-590-65 |
| R | 4.7 Ohms, 1/4 W | Q | MRF509 |
| | | Board Material | 1/16" Teflon-Fiberglass, $\epsilon_r$ = 2.5 |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 10 Ω) | $BV_{CER}$ | 55 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 55 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 0.02 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain-Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 500 | 1000 | – | MHz |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 2.2 | 3.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 1.0 W, $V_{CC}$ = 28 Vdc, f = 400 MHz) | $G_{PE}$ | 10 | – | – | dB |
| Collector Efficiency ($P_{out}$ = 1.0 W, $V_{CC}$ = 28 Vdc, f = 400 MHz) | η | 40 | – | – | % |

**FIGURE 2 — OUTPUT POWER versus INPUT POWER**

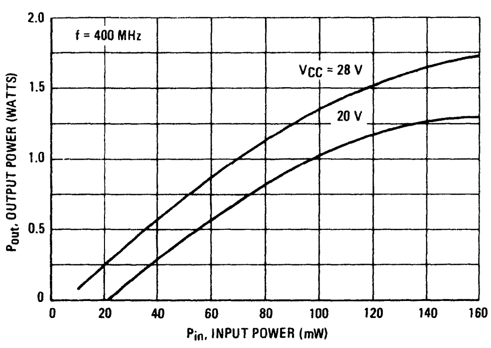



**FIGURE 3 — OUTPUT POWER versus FREQUENCY**

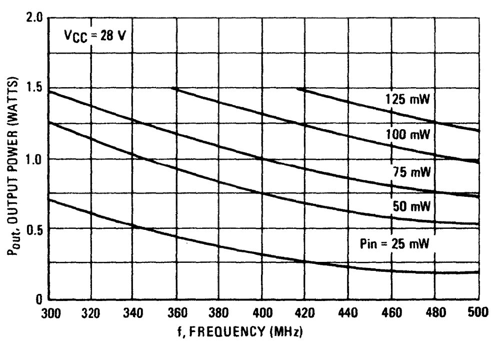


FIGURE 4 – CURRENT-GAIN-BANDWIDTH PRODUCT

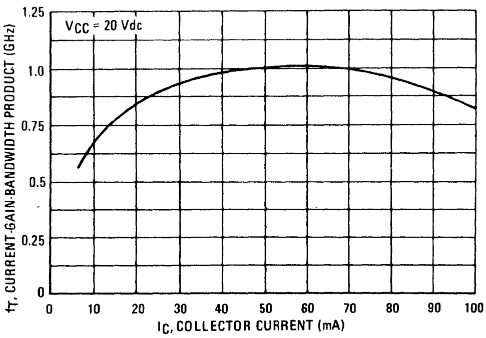



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE

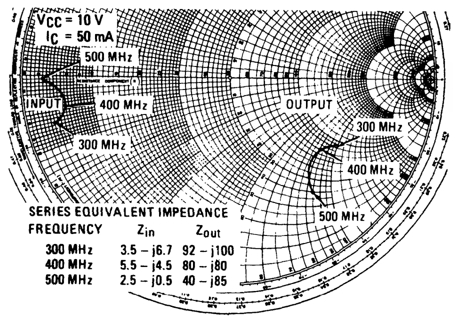



FIGURE 6 – S11, INPUT REFLECTION COEFFICIENT

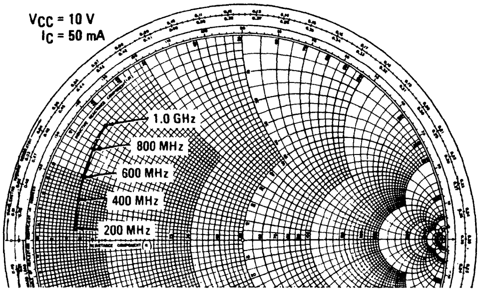



FIGURE 7 – S22, OUTPUT REFLECTION COEFFICIENT

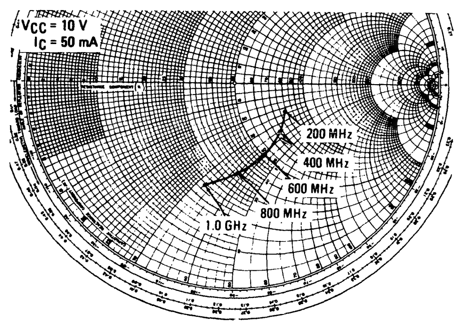



FIGURE 8 – S12, REVERSE TRANSMISSION COEFFICIENT

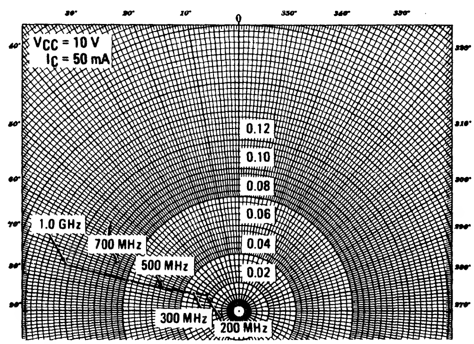



FIGURE 9 – S21, FORWARD TRANSMISSION COEFFICIENT

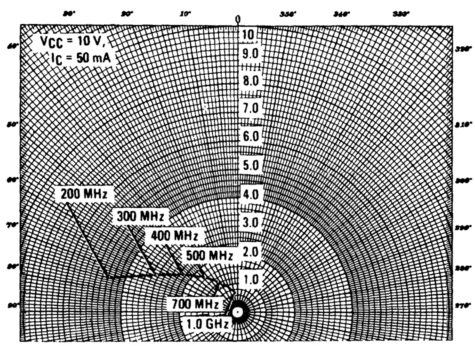
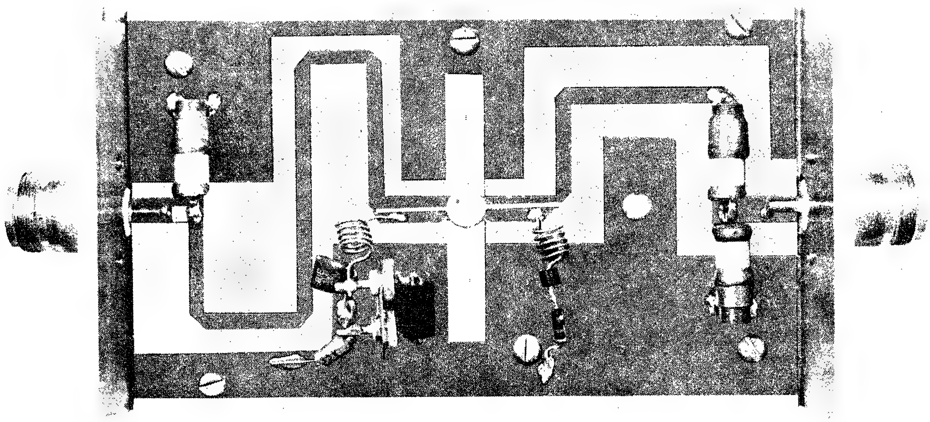


FIGURE 10 – 400 MHz TEST CIRCUIT



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF525

## The RF Line

100–500 MHz BROADBAND

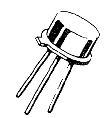
HIGH FREQUENCY TRANSISTOR

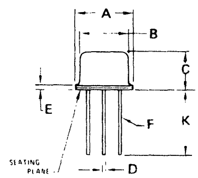
NPN SILICON

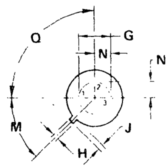
### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed specifically for broadband linear amplifier stages in the 100–500 MHz frequency range.

- Guaranteed Performance at 225–400 MHz, 26 Vdc
  Minimum Gain = 13 dB
  Maximum NF = 4.0 dB
- Third Order Intercept +35 dBm (Typ)
- Common Emitter TO-39 Package
- S-Parameter Characterization






STYLE 5
PIN 1. COLLECTOR
PIN 2. BASE
PIN 3. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |

NOTE: The pin configuration of this version of the TO-39 package differs from the common isolated emitter type.
All JEDEC dimensions and notes apply.

CASE 79-03
TO-39

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage ($R_{BE}$ = 330 Ω) | $V_{CER}$ | 25 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 150 | mAdc |
| Total Power Dissipation @ $T_A$ = 50°C<br>Derate above 50°C | $P_D$ | 2.5<br>0.017 | Watts<br>W/°C |
| Operating Junction Temperature | $T_J$ | +175 | °C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

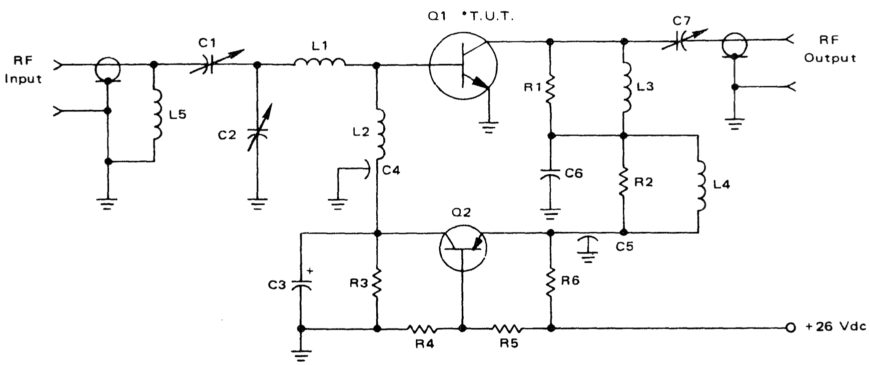
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 60 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 330 Ohms) | $BV_{CER}$ | 25 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mA, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mA, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 100 | μA |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 80 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 60 | – | 175 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 20 Vdc, f = 200 MHz) | $f_T$ | 2.2 | 2.5 | – | GHz |
| Output Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | 4.0 | pF |
| **FUNCTIONAL TEST – BROADBAND (Figure 1)** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 26 Vdc, $P_{in}$ = 0 dBm, f = 400 MHz) | $G_{PE}$ | 13 | 14 | – | dB |
| Broadband Noise Figure ($V_{CE}$ = 26 Vdc, f = 400 MHz) | NF | – | – | 4.0 | dB |

**FIGURE 1 – 225 to 400 MHz BROADBAND TEST CIRCUIT SCHEMATIC**




C1, C2 – 2.5-11 pF Erie Ceramic Variable
C3 – 47 μF 6.0 Volt Electrolytic
C4, C5 – 1000 pF Feedthru
C6 – 470 pF Ceramic Chip
C7 – 5.5-18 pF Erie Ceramic Variable

R1 – 150 Ω 1/8 Watt Carbon
R2 – 100 Ω 1/8 Watt Carbon
R3, R4 – 10 kΩ 1/8 Watt Carbon
R5 – 3.3 kΩ 1/8 Watt Carbon

R6 – 120 Ω 1/2 Watt Carbon

L1 – 1 Turn #24, 0.125 mil ID
L2, L4 – 0.47 μH Molded Choke
L3 – 2 Turns #24, 0.125 mil ID
L5 – 4 Turns #24, 0.125 mil ID

Q2 – 2N2907A

•Transistor Under Test
$I_E$ = 47 mAdc (Nominal)

FIGURE 2 — COMMON-EMITTER POWER GAIN ($G_{max}$) versus FREQUENCY

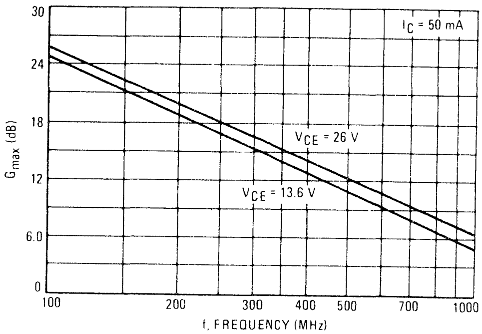



FIGURE 3 — CURRENT GAIN BANDWIDTH PRODUCT versus COLLECTOR CURRENT

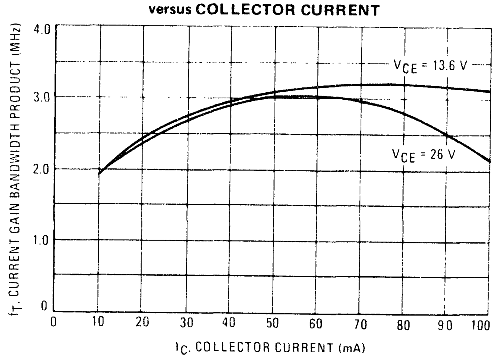



FIGURE 4 — BROADBAND AMPLIFIER RESPONSE

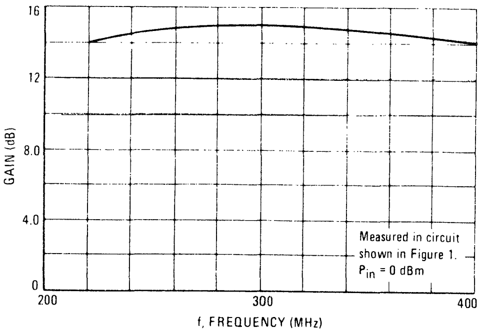



FIGURE 5 — 1.0 dB GAIN COMPRESSION OUTPUT versus FREQUENCY

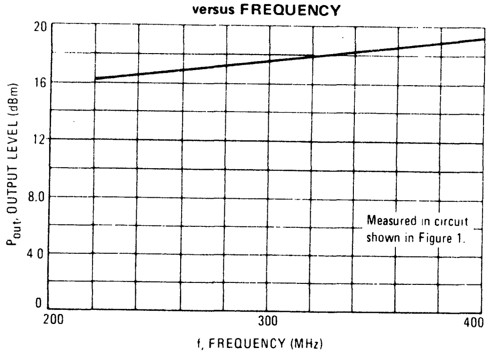
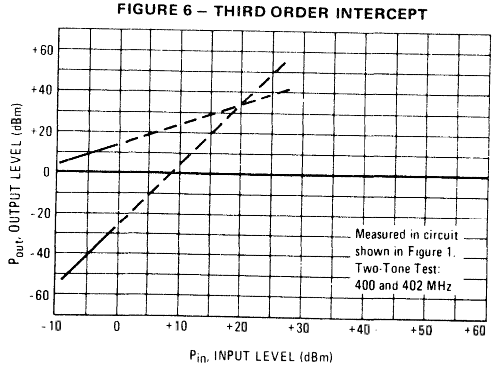



FIGURE 6 — THIRD ORDER INTERCEPT



S–PARAMETERS

| $V_{CE}$ (Volts) | $I_C$ (mA) | Frequency (MHz) | S11 |  | S21 |  | S12 |  | S22 |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | \|S11\| | ∠φ | \|S21\| | ∠φ | \|S12\| | ∠φ | \|S22\| | ∠φ |
| 13.6 | 10 | 100 | 0.388 | -111 | 12.318 | 107 | 0.032 | 61 | 0.597 | -24 |
|  |  | 200 | 0.331 | -151 | 6.768 | 88 | 0.049 | 68 | 0.480 | -25 |
|  |  | 300 | 0.337 | -171 | 4.650 | 77 | 0.072 | 73 | 0.443 | -31 |
|  |  | 400 | 0.344 | 176 | 3.580 | 68 | 0.096 | 78 | 0.442 | -40 |
|  |  | 500 | 0.349 | 166 | 2.889 | 59 | 0.125 | 80 | 0.459 | -47 |
|  | 20 | 100 | 0.287 | -125 | 14.160 | 103 | 0.030 | 67 | 0.516 | -24 |
|  |  | 200 | 0.263 | -160 | 7.585 | 86 | 0.053 | 73 | 0.414 | -23 |
|  |  | 300 | 0.275 | -177 | 5.167 | 76 | 0.078 | 76 | 0.378 | -30 |
|  |  | 400 | 0.288 | 172 | 3.968 | 68 | 0.104 | 77 | 0.378 | -38 |
|  |  | 500 | 0.293 | 164 | 3.214 | 60 | 0.135 | 78 | 0.396 | -45 |
|  | 50 | 100 | 0.206 | -140 | 15.745 | 99 | 0.029 | 74 | 0.446 | -24 |
|  |  | 200 | 0.208 | -171 | 8.299 | 84 | 0.056 | 76 | 0.358 | -21 |
|  |  | 300 | 0.226 | 176 | 5.612 | 75 | 0.084 | 76 | 0.324 | -27 |
|  |  | 400 | 0.235 | 169 | 4.307 | 68 | 0.113 | 77 | 0.326 | -36 |
|  |  | 500 | 0.243 | 161 | 3.488 | 60 | 0.114 | 76 | 0.345 | -42 |
|  | 100 | 100 | 0.179 | -151 | 15.931 | 98 | 0.029 | 77 | 0.430 | -22 |
|  |  | 200 | 0.187 | -177 | 8.293 | 85 | 0.058 | 80 | 0.358 | -19 |
|  |  | 300 | 0.203 | 171 | 5.626 | 77 | 0.087 | 80 | 0.330 | -25 |
|  |  | 400 | 0.212 | 164 | 4.276 | 70 | 0.115 | 80 | 0.338 | -33 |
|  |  | 500 | 0.213 | 157 | 3.456 | 63 | 0.147 | 79 | 0.364 | -39 |
| 26 | 10 | 100 | 0.454 | -100 | 13.580 | 105 | 0.027 | 58 | 0.625 | -15 |
|  |  | 200 | 0.313 | -138 | 7.339 | 88 | 0.040 | 67 | 0.552 | -17 |
|  |  | 300 | 0.291 | -161 | 4.989 | 78 | 0.060 | 76 | 0.532 | -23 |
|  |  | 400 | 0.287 | -175 | 3.826 | 70 | 0.080 | 84 | 0.544 | -30 |
|  |  | 500 | 0.287 | 173 | 3.096 | 63 | 0.106 | 89 | 0.570 | -36 |
|  | 20 | 100 | 0.313 | -105 | 15.191 | 102 | 0.025 | 62 | 0.566 | -14 |
|  |  | 200 | 0.220 | -144 | 8.086 | 87 | 0.044 | 73 | 0.509 | -15 |
|  |  | 300 | 0.213 | -166 | 5.487 | 77 | 0.067 | 78 | 0.489 | -20 |
|  |  | 400 | 0.215 | -178 | 4.204 | 71 | 0.092 | 83 | 0.498 | -28 |
|  |  | 500 | 0.214 | 170 | 3.404 | 64 | 0.116 | 86 | 0.523 | -34 |
|  | 50 | 100 | 0.165 | -117 | 16.375 | 102 | 0.026 | 71 | 0.529 | -14 |
|  |  | 200 | 0.139 | -157 | 8.695 | 87 | 0.048 | 78 | 0.471 | -14 |
|  |  | 300 | 0.151 | -176 | 5.882 | 78 | 0.073 | 80 | 0.449 | -20 |
|  |  | 400 | 0.157 | 173 | 4.494 | 71 | 0.098 | 82 | 0.458 | -27 |
|  |  | 500 | 0.158 | 164 | 3.659 | 65 | 0.124 | 84 | 0.485 | -32 |
|  | 100 | 100 | 0.215 | -147 | 13.156 | 103 | 0.023 | 72 | 0.602 | -14 |
|  |  | 200 | 0.212 | -176 | 7.220 | 88 | 0.044 | 82 | 0.536 | -17 |
|  |  | 300 | 0.222 | 171 | 4.951 | 79 | 0.069 | 84 | 0.507 | -24 |
|  |  | 400 | 0.230 | 164 | 3.851 | 72 | 0.093 | 87 | 0.513 | -31 |
|  |  | 500 | 0.233 | 156 | 3.123 | 64 | 0.123 | 89 | 0.534 | -36 |

**MOTOROLA**
**Semiconductors**
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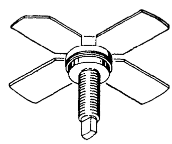
# MRF5174

## The RF Line

2 W – 400 MHz

RF POWER
TRANSISTOR

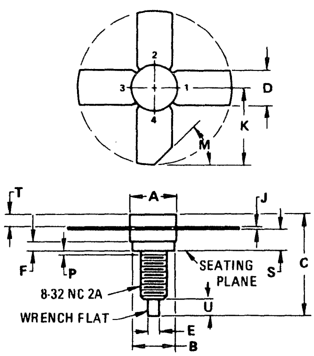
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed primarily for wideband large-signal driver and pre-driver amplifier stages in the 200-600 MHz frequency range.

- Specified 28-Volt, 400-MHz Characteristics –
  Output Power = 2.0 Watts
  Minimum Gain = 12 dB
  Efficiency = 50%
- Characterized from 200 to 600 MHz
- Includes Series Equivalent Impedances




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.51 | 0.590 | 0.650 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.40 | 1.65 | 0.055 | 0.065 |
| F | 1.52 | – | 0.060 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |

CASE 244-04

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 33 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.5 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C (1)<br>Derate above 25°C | $P_D$ | 5.0<br>28 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

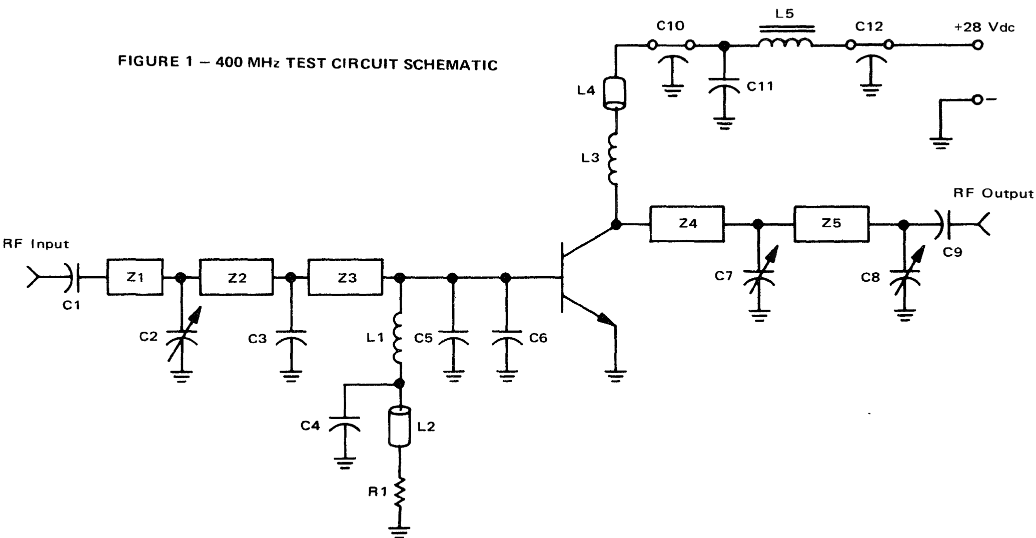
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 25 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 33 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 60 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 30 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 100 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 8.0 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 28 Vdc, $P_{out}$ = 2.0 W, f = 400 MHz) | $G_{PE}$ | 12 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 28 Vdc, $P_{out}$ = 2.0 W, f = 400 MHz) | $\eta$ | 50 | – | – | % |

FIGURE 1 – 400 MHz TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1, 9 | – 0.02 µF Chip | L1 | – 3.9 µH Molded Choke |
| C2 | – 0.0-10 pF Johanson 2951 | L2, 4 | – Ferrite Bead Ferroxcube 56-590-65-3B |
| C3 | – 25 pF Unelco | L3 | – 0.15 µH Molded Choke |
| C4 | – 100 pF Unelco | L5 | – Ferrite Choke VK200-20-4B |
| C5, 6 | – 5.0 pF ATC 100 mil Chip | | |
| C7, 8 | – 0.8-20 pF Johanson 3906 | Z1 – 1.7 cm | Microstrip Length |
| C10, 12 | – 680 pF Feedthru | Z2 – 1.5 cm | from Center Line |
| C11 | – 1.0 µF Tantalum 35 V | Z3 – 1.5 cm | of Tuning Capacitors |
| | | Z4 – 3.6 cm | |
| R1 | – 2.7 Ohm 1/2 Watt | Z5 – 3.3 cm | See photograph |

FIGURE 2 – OUTPUT POWER versus FREQUENCY

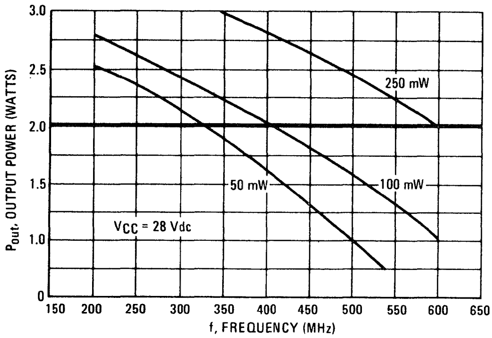



FIGURE 3 – OUTPUT POWER versus INPUT POWER

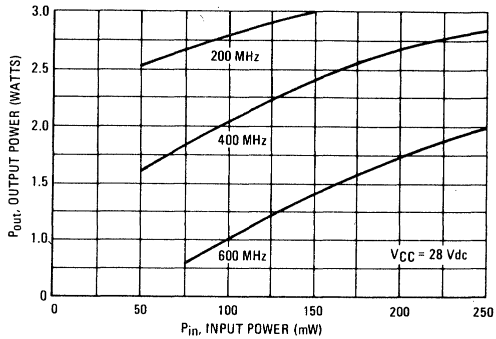



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

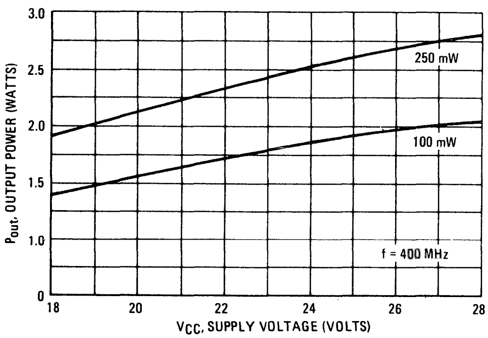
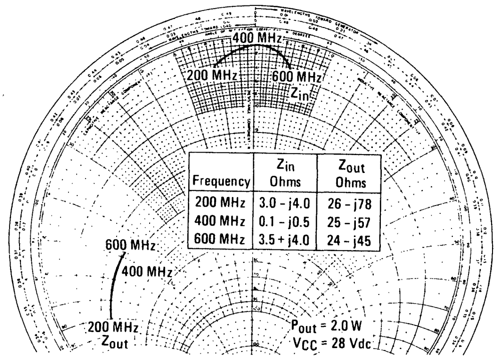
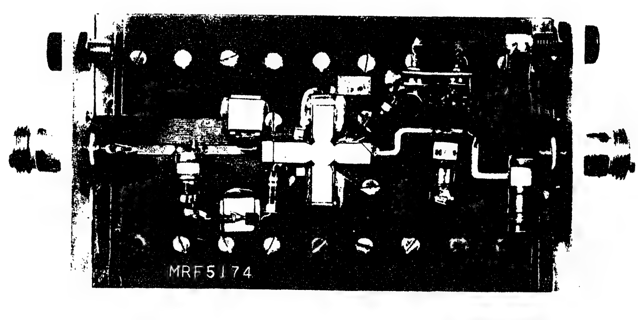


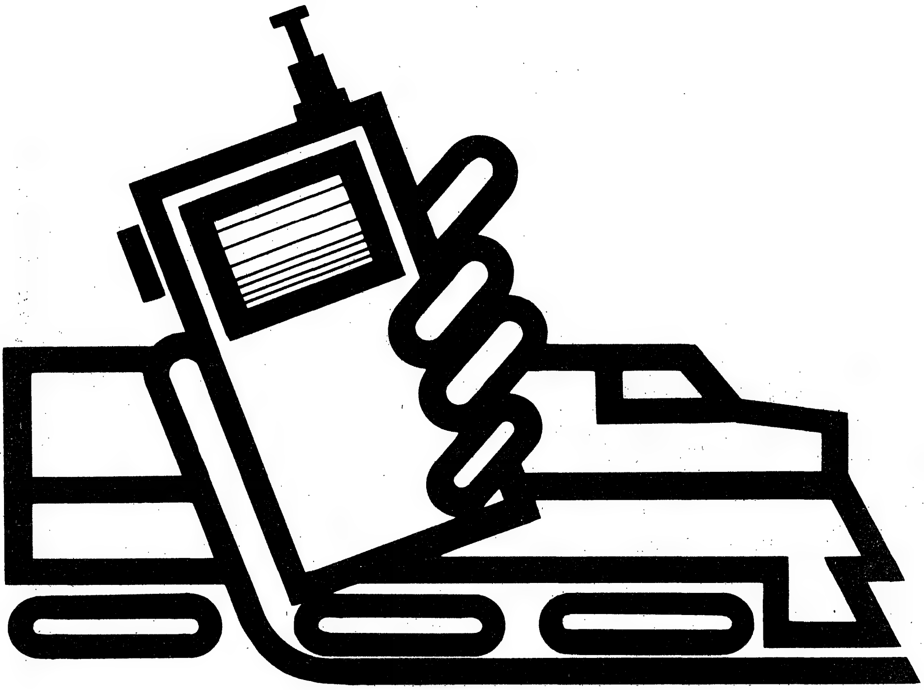

FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| Frequency | $Z_{in}$ Ohms | $Z_{out}$ Ohms |
|---|---|---|
| 200 MHz | 3.0 - j4.0 | 26 - j78 |
| 400 MHz | 0.1 - j0.5 | 25 - j57 |
| 600 MHz | 3.5 + j4.0 | 24 - j45 |

FIGURE 6 – 400 MHz TEST CIRCUIT





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# 2N3948

12

## The RF Line

1.0 W – 400 MHz

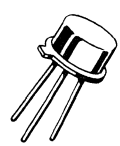
HIGH FREQUENCY
TRANSISTOR

NPN SILICON

## NPN SILICON HIGH-FREQUENCY TRANSISTOR

. . . designed for amplifier applications in industrial and commercial equipment. Suitable for use as output, driver or pre-driver stages in UHF equipment.

- Specified 400 MHz, 13.6 Vdc Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 6.0 dB
  Efficiency = 45%



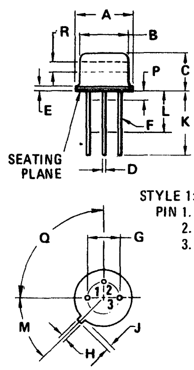
### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 1.0<br>5.71 | Watt<br>mW/$^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 35 | $^oC/W$ |
| Thermal Resistance, Junction to Ambient | $R_{\theta JA}$ | 175 | $^oC/W$ |

*Indicates JEDEC Registered Data




STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | $45^o$ NOM | | $45^o$ NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | $90^o$ NOM | | $90^o$ NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

## *ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 20 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | Vdc |
| Collector Cutoff Current | $I_{CBO}$ | | | μAdc |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | | – | 0.1 | |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0, $T_A$ = 150°C) | | – | 100 | |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 15 | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain – Bandwidth Product ($I_E$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 700 | – | MHz |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 4.5 | pF |
| **FUNCTIONAL TEST** | | | | |
| Power Gain ($V_{CC}$ = 13.6 Vdc, f = 400 MHz, $P_{in}$ = 0.25 W) | $G_{pe}$ | 6.0 | – | dB |
| Output Power ($V_{CC}$ = 13.6 Vdc, f = 400 MHz, $P_{in}$ = 0.25 W) | $P_{out}$ | 1.0 | – | Watt |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, f = 400 MHz, $P_{in}$ = 0.25 W) | $\eta$ | 45 | – | % |

*Indicates JEDEC Registered Data

**FIGURE 1 – 400 MHz RF AMPLIFIER TEST CIRCUIT**

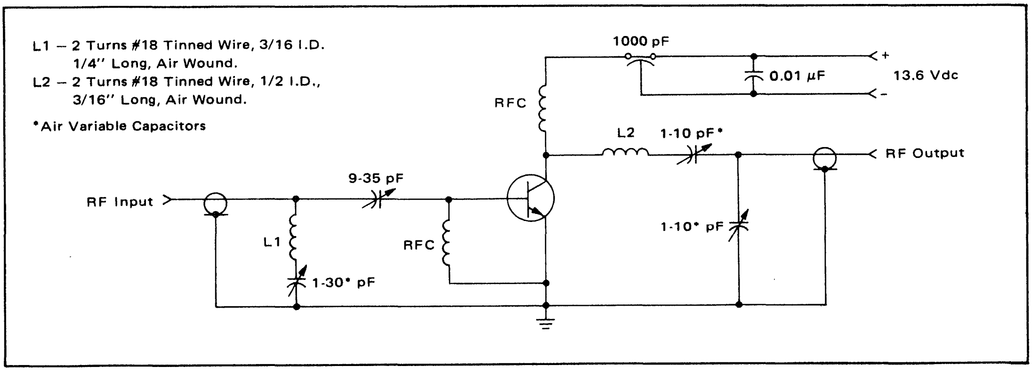



**FIGURE 2 – OUTPUT POWER versus FREQUENCY**

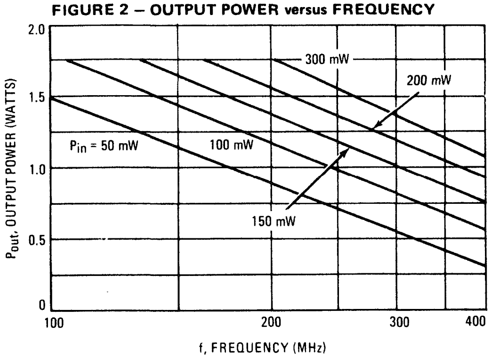
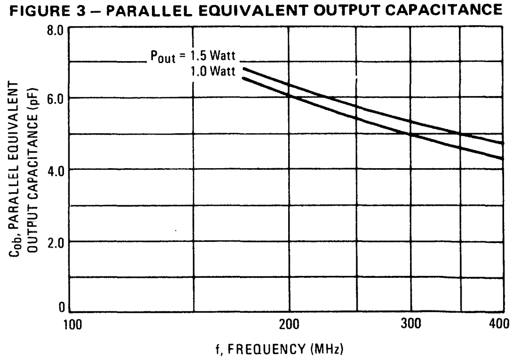



**FIGURE 3 – PARALLEL EQUIVALENT OUTPUT CAPACITANCE**



MOTOROLA
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BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5944
# 2N5945
# 2N5946

12

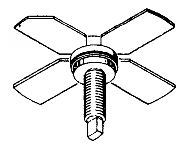
## The RF Line

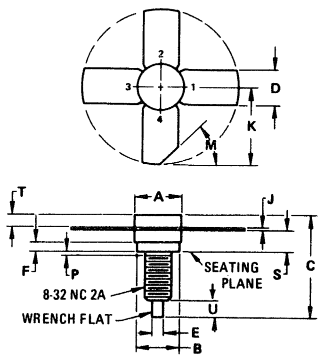
### NPN SILICON RF POWER TRANSISTORS

. . . designed for 7.0 to 15 Volts, UHF large signal amplifier applications required in industrial and commercial FM equipment operating in the 400 to 960 MHz range.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Power Output = 2.0 W – 2N5944
  4.0 W – 2N5945
  10 W – 2N5946
  Minimum Gain = 9.0 dB – 2N5944
  8.0 dB – 2N5945
  6.0 dB – 2N5946
  Efficiency = 60% Minimum
- RF ballasting provides protection against device damage due to load mismatch
- Characterized with series equivalent large-signal impedance parameters

**2.0, 4.0, 10 W – 470 MHz**
**RF POWER TRANSISTORS**
**NPN SILICON**






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.51 | 0.590 | 0.650 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.40 | 1.65 | 0.055 | 0.065 |
| F | 1.52 | – | 0.060 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |

CASE 244-04

### MAXIMUM RATINGS

| Rating | Symbol | 2N5944 | 2N5945 | 2N5946 | Unit |
|---|---|---|---|---|---|
| *Collector-Emitter Voltage | $V_{CEO}$ | ← 16 → | | | Vdc |
| *Collector-Base Voltage | $V_{CBO}$ | ← 36 → | | | Vdc |
| *Emitter-Base Voltage | $V_{EBO}$ | ← 4.0 → | | | Vdc |
| *Collector Current – Continuous | $I_C$ | 0.4 | 0.8 | 2.0 | Adc |
| *Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 5.0<br>28.5 | 15<br>85.5 | 37.5<br>214 | Watts<br>mW/°C |
| *Storage Temperature Range | $T_{stg}$ | ← –65 to +200 → | | | °C |
| Stud Torque (2) | — | ← 6.5 → | | | in-lbs. |

*Indicates JEDEC Registered Data
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.
(2) For repeated assembly use 5 in-lbs.

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*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | |
| Collector-Emitter Breakdown Voltage | | $BV_{CEO}$ | | | | Vdc |
| ($I_C$ = 50 mAdc, $I_B$ = 0) | 2N5944 | | 16 | – | – | |
| ($I_C$ = 100 mAdc, $I_B$ = 0) | 2N5945 | | 16 | – | – | |
| ($I_C$ = 200 mAdc, $I_B$ = 0) | 2N5946 | | 16 | – | – | |
| Collector-Emitter Breakdown Voltage | | $BV_{CES}$ | | | | Vdc |
| ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | 2N5944 | | 36 | – | – | |
| ($I_C$ = 100 mAdc, $V_{BE}$ = 0) | 2N5945 | | 36 | – | – | |
| ($I_C$ = 200 mAdc, $V_{BE}$ = 0) | 2N5946 | | 36 | – | – | |
| Emitter-Base Breakdown Voltage | | $BV_{EBO}$ | | | | Vdc |
| ($I_E$ = 1.0 mAdc, $I_C$ = 0) | 2N5944 | | 4.0 | – | – | |
| ($I_E$ = 2.0 mAdc, $I_C$ = 0) | 2N5945 | | 4.0 | – | – | |
| ($I_E$ = 4.0 mAdc, $I_C$ = 0) | 2N5946 | | 4.0 | – | – | |
| Collector Cutoff Current | | $I_{CES}$ | | | | mAdc |
| ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 55°C) | 2N5944 | | – | 0.2 | 10 | |
| | 2N5945,2N5946 | | – | 0.5 | 20 | |
| Collector Cutoff Current | | $I_{CBO}$ | | | | mAdc |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | 2N5944,2N5945 | | – | – | 1.0 | |
| | 2N5946 | | – | – | 2.0 | |
| **ON CHARACTERISTICS** | | | | | | |
| DC Current Gain | | $h_{FE}$ | | | | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | 2N5944 | | 20 | 80 | – | |
| ($I_C$ = 200 mAdc, $V_{CE}$ = 5.0 Vdc) | 2N5945 | | 20 | 80 | – | |
| ($I_C$ = 500 mAdc, $V_{CE}$ = 5.0 Vdc) | 2N5946 | | 20 | 80 | – | |
| **DYNAMIC CHARACTERISTICS** | | | | | | |
| Output Capacitance | | $C_{ob}$ | | | | pF |
| ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | 2N5944 | | – | 11 | 15 | |
| | 2N5945 | | | 18 | 25 | |
| | 2N5946 | | – | 38 | 45 | |
| **FUNCTIONAL TEST (Figure 20)** | | | | | | |
| Common-Emitter Amplifier Power Gain | | $G_{PE}$ | | | | dB |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 2.0 W, $I_C$(max) = 267 mAdc, f = 470 MHz) | 2N5944 | | 9.0 | 10 | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 4.0 W, $I_C$(max) = 533 mAdc, f = 470 MHz) | 2N5945 | | 8.0 | 9.0 | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, $I_C$(max) = 1.33 Adc, f = 470 MHz) | 2N5946 | | 6.0 | 7.0 | – | |
| Collector Efficiency | | $\eta$ | | | | % |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 2.0 W, $I_C$(max) = 240 mAdc, f = 470 MHz) | 2N5944 | | 60 | – | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 4.0 W, $I_C$(max) = 500 mAdc, f = 470 MHz) | 2N5945 | | 60 | – | – | |
| ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 10 W, $I_C$(max) = 1.3 Adc, f = 470 MHz) | 2N5946 | | 60 | – | – | |

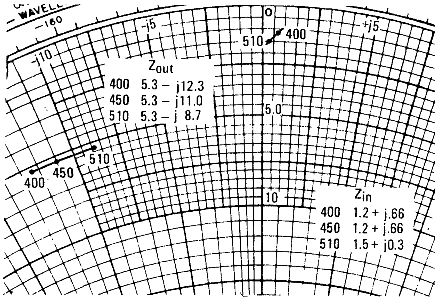
*Indicates JEDEC Registered Data

These devices are available in various packages, such as a studless stripline package, TO-39, and also in chip form on beryllium oxide carriers for hybrid assemblies.

For further information, contact your nearest Motorola representative or the factory representative.

## 2N5944
## TYPICAL PERFORMANCE DATA

FIGURE 1 – SERIES EQUIVALENT IMPEDANCE




$V_{CC}$ = 12.5 Vdc, $P_{out}$ = 2.0 W

FIGURE 2 – OUTPUT POWER versus SUPPLY VOLTAGE

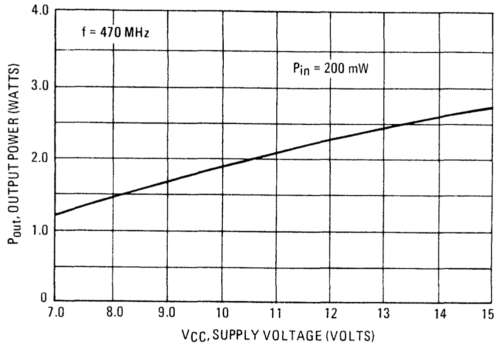



FIGURE 3 – OUTPUT POWER versus INPUT POWER

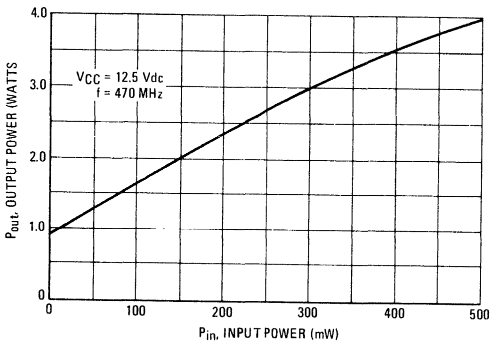



FIGURE 4 – OUTPUT POWER versus FREQUENCY

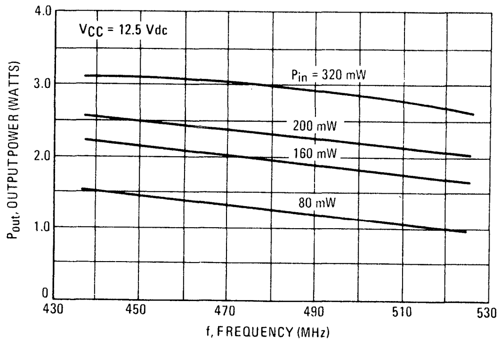



FIGURE 5 – OUTPUT POWER versus INPUT POWER

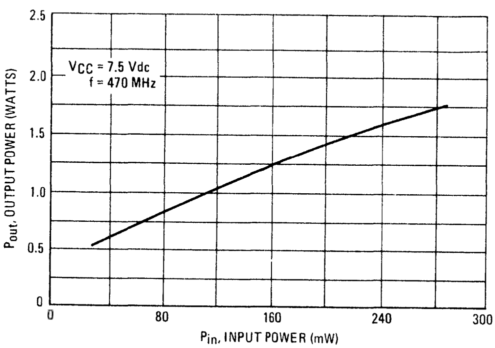
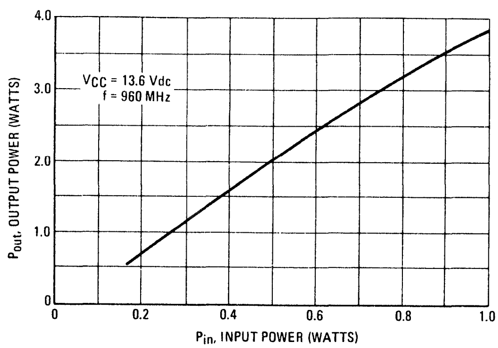



FIGURE 6 – OUTPUT POWER versus INPUT POWER



## 2N5945
## TYPICAL PERFORMANCE DATA

FIGURE 7 – SERIES EQUIVALENT IMPEDANCE

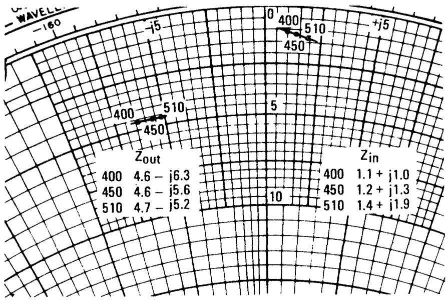



FIGURE 8 – OUTPUT POWER versus SUPPLY VOLTAGE

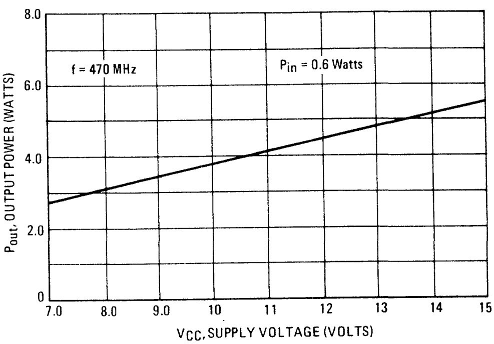



FIGURE 9 – OUTPUT POWER versus INPUT POWER

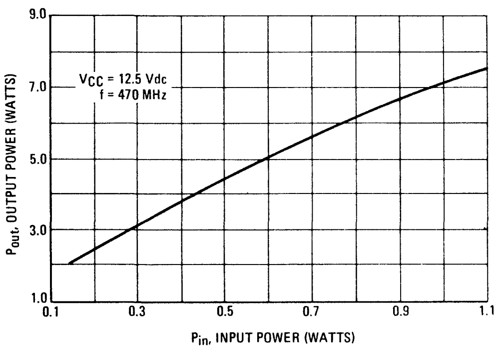



FIGURE 10 – OUTPUT POWER versus FREQUENCY

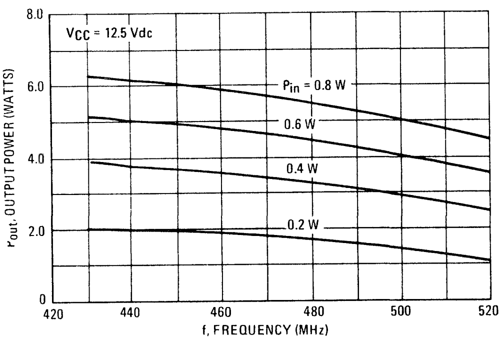



FIGURE 11 – OUTPUT POWER versus INPUT POWER

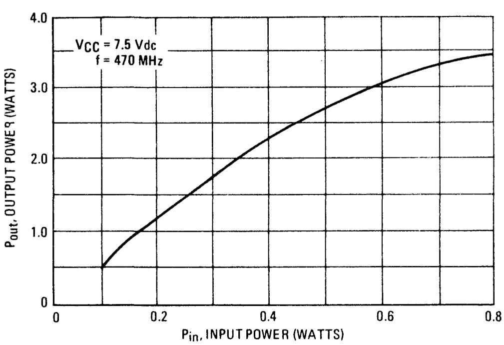
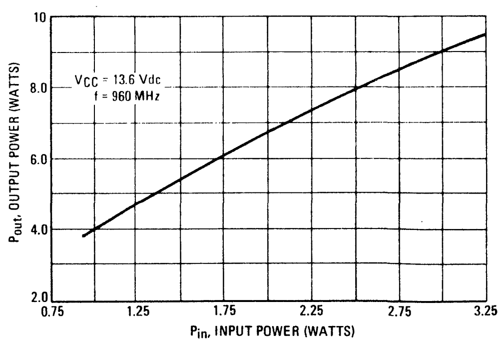
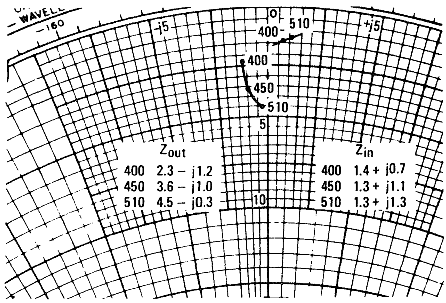



FIGURE 12 – OUTPUT POWER versus INPUT POWER



## 2N5946
## TYPICAL PERFORMANCE DATA

FIGURE 13 – SERIES EQUIVALENT IMPEDANCE




$V_{CC}$ = 12.5 Vdc, $P_{out}$ = 12 W

FIGURE 14 – OUTPUT POWER versus SUPPLY VOLTAGE

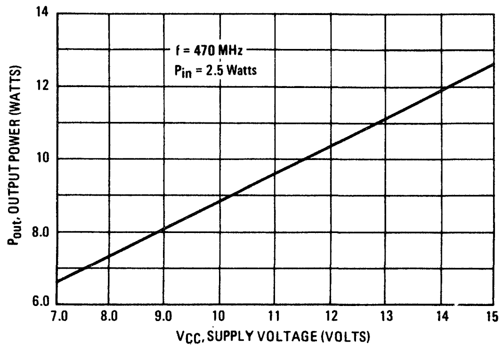



FIGURE 15 – OUTPUT POWER versus INPUT POWER

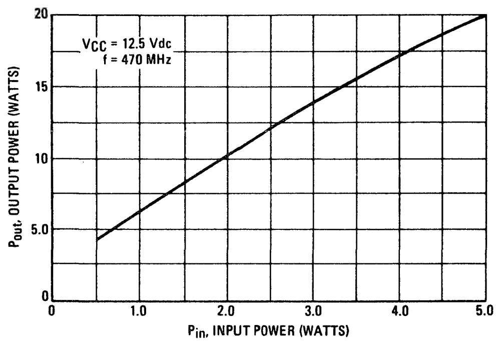



FIGURE 16 – OUTPUT POWER versus FREQUENCY

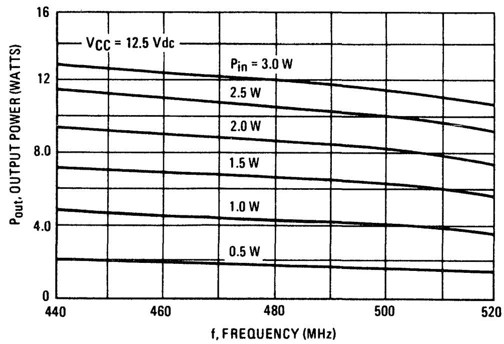
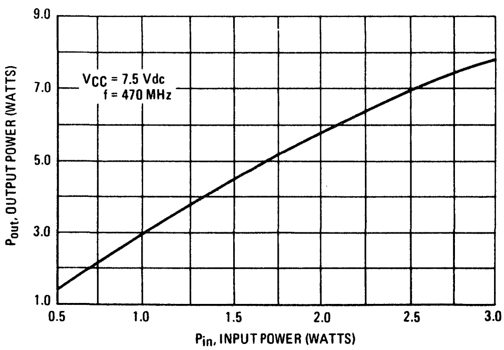
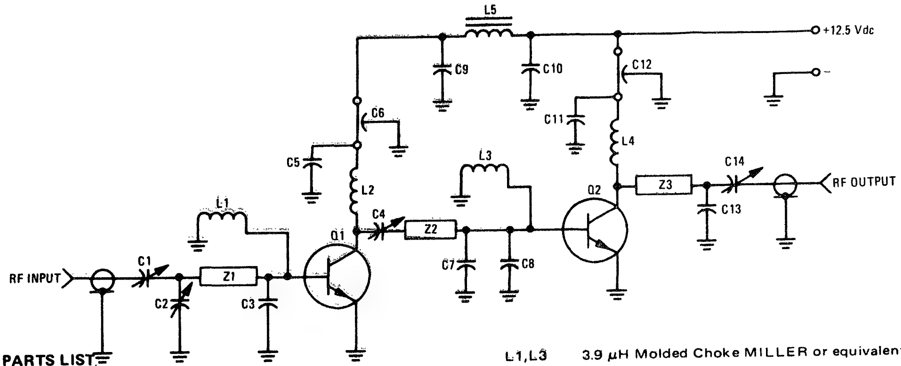



FIGURE 17 – OUTPUT POWER versus INPUT POWER



## 10-WATT BROADBAND UHF AMPLIFIER

FIGURE 18




**PARTS LIST**

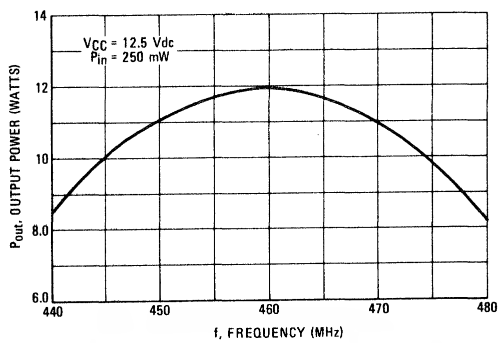
| | |
|---|---|
| C1,C2,C4,C13,C14 | 0.9-7.0 pF ARCO 400 or equivalent |
| C3,C7,C8 | 25 pF UNELCO or equivalent |
| C5,C11 | 0.1 µF Ceramic 35 V |
| C6,C12 | 680 pF ALLEN BRADLEY Feedthru |
| C9,C10 | 1.0 µF, 35 V Tantalum |
| L1,L3 | 3.9 µH Molded Choke MILLER or equivalent |
| L2,L4 | 5 Turns #18 AWG Enameled 0.2" I.D. |
| L5 | FERROXCUBE Ferrite Choke VK200 20/4B |
| Z1,Z2,Z3 | Microstrip Lines (See Template Below) |
| Q1 | 2N5944 |
| Q2 | 2N5946 |

**10 W AMPLIFIER PERFORMANCE**

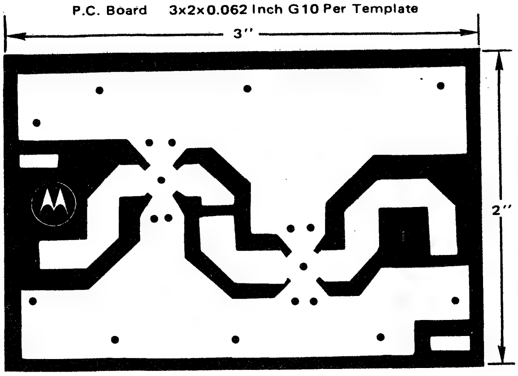
$V_{CC}$ = 12.5 Vdc

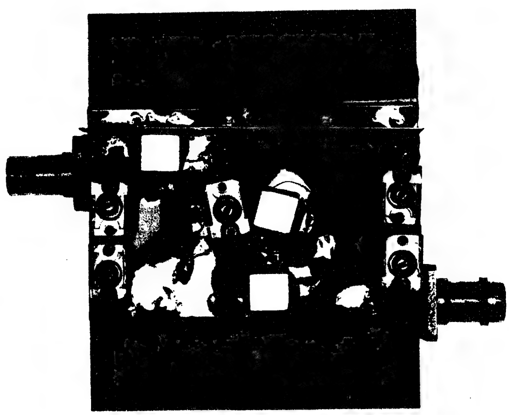
| Frequency MHz | $P_{in}$ mW | $P_{out}$ W | $I_C$ Amp |
|---|---|---|---|
| 440 | 250 | 8.5 | 1.5 |
| 450 | 250 | 11 | 1.6 |
| 460 | 250 | 12 | 1.6 |
| 470 | 250 | 10.9 | 1.5 |
| 480 | 250 | 8.2 | 1.2 |

FIGURE 19 – OUTPUT POWER versus FREQUENCY



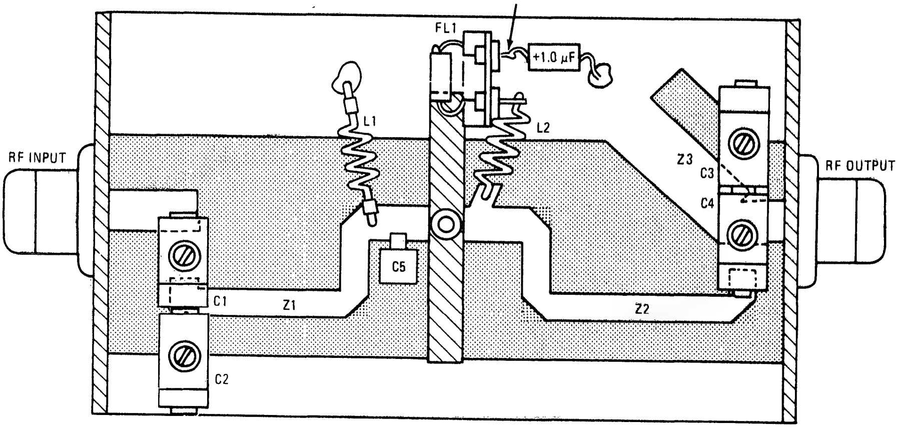

P.C. Board 3x2x0.062 Inch G10 Per Template



## 470 MHz TEST CIRCUIT

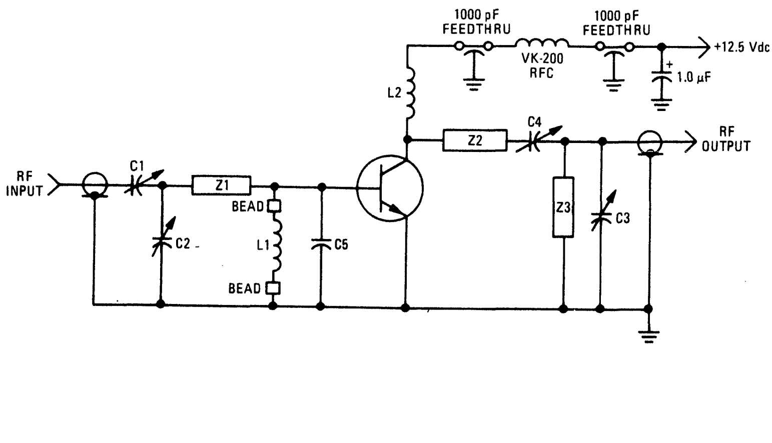
FIGURE 20




C1,2 1.0-25 pF ARCO 421 OR EQUIVALENT
C3,4 1.0-25 pF ARCO 421 OR EQUIVALENT
L1,2 7 TURNS #22 AWG, 0.2" I.D.
FERRITE BEADS FERROXCUBE 56-590-65-3B
AS SHOWN ON L1
FL1 DC SUPPLY FILTER
2-1000 pF FT CAPACITOR
1-1.0 μF, 35 V CAPACITOR
1-CHOKE FERROXCUBE VK 200-20-4B

CONNECTORS ARE TYPE "N"
BOARD IS GLASS TEFLON
3" x 5" x 0.060"
MOUNTING PLATE IS 3" x 5" x 0.75"

FIGURE 21



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6256

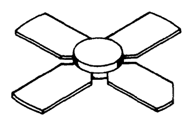
## The RF Line

### NPN SILICON RF POWER TRANSISTOR

... designed for 12.5 Volt, VHF/UHF large signal Amplifier/Multiplier applications required in industrial and commercial FM equipment operating to 520 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics
  Power Output = 0.5 Watts
  Minimum Gain = 7.0 dB
  Efficiency = 60%
- Characterized with series equivalent large signal impedance parameters
- Capable of Output Power @ 1.0 Watt

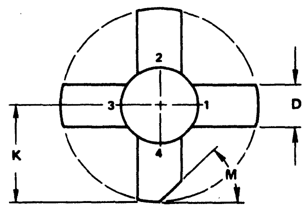
0.5 WATT – 470 MHz
RF POWER
TRANSISTOR
NPN SILICON

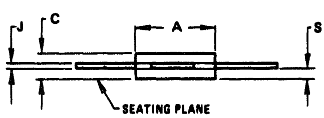


*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 0.4 | Adc |
| Total Continuous Device Dissipation @ $T_C = 25^oC$ – Derate above $25^oC$ | $P_D$ | 2.0<br>11.4 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

* Indicates JEDEC Registered Data



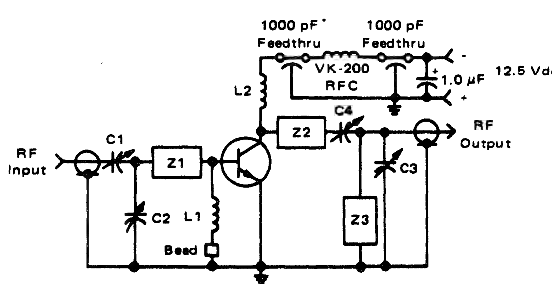




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| C | 2.84 | 3.45 | 0.112 | 0.136 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| S | 1.40 | 1.65 | 0.055 | 0.065 |

CASE 249-05

FIGURE 1 – 470 MHz TEST CIRCUIT SCHEMATIC




NOTE: Test Circuit Layout and Component Descriptions Shown in Figure 6.

*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_A$ = 125°C) | $I_{CES}$ | – | – | 5.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| Dc Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 80 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 6.0 | 8.0 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figures 1, 6) ($P_{out}$ = 0.5 W, $V_{CC}$ = 12.5 Vdc, f = 470 MHz) | $G_{PE}$ | 7.0 | 9.0 | – | dB |
| Collector Efficiency (Figures 1, 6) ($P_{out}$ = 0.5 W, $V_{CC}$ = 12.5 Vdc, f = 470 MHz) | $\eta$ | 60 | 70 | – | % |

*Indicates JEDEC Registered Data.

Typical Output Power curves were measured in circuit shown in Figure 6.

FIGURE 2 – OUTPUT POWER versus FREQUENCY

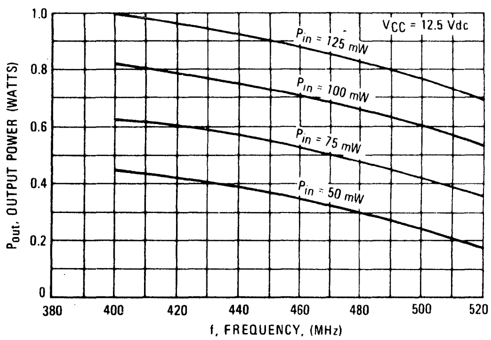



FIGURE 3 – OUTPUT POWER versus INPUT POWER

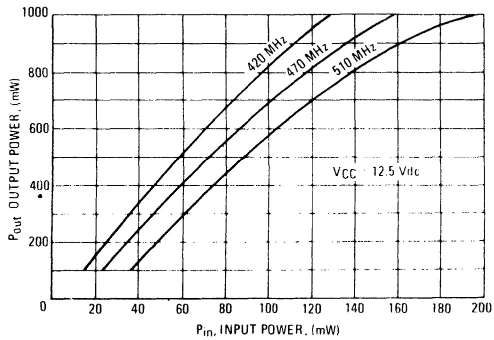


FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

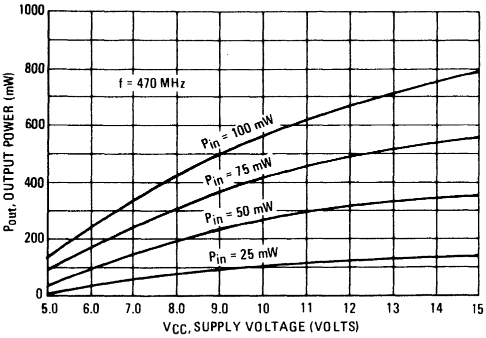



FIGURE 5 – SERIES EQUIVALENT INPUT and OUTPUT IMPEDANCE

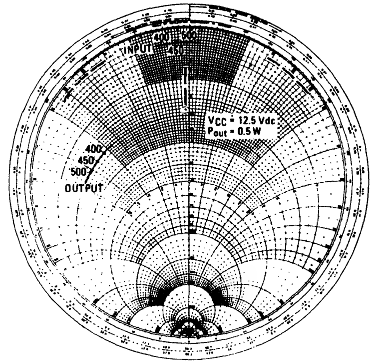
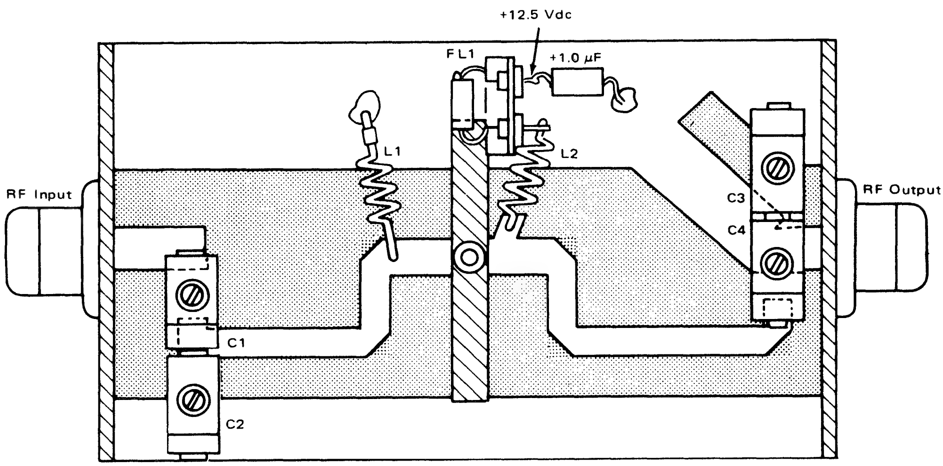


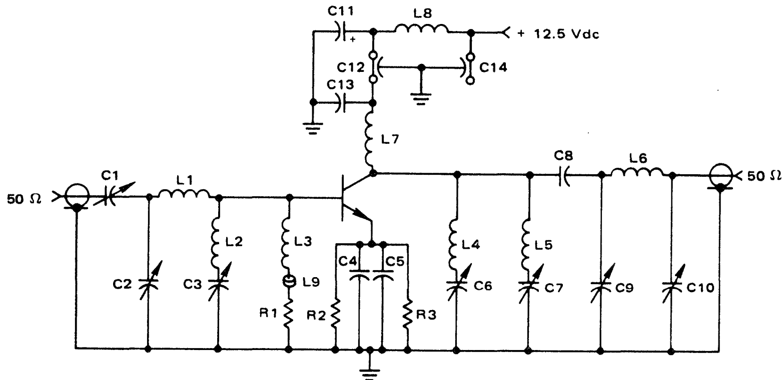

FIGURE 6 – 470 MHz TEST CIRCUIT LAYOUT
(See Figure 1 for Schematic Diagram)




| | |
|---|---|
| C1,C2 | 1.0-25 pF ARCO 421 or Equivalent |
| C3, C4 | 1.0-25 pF ARCO 421 or Equivalent |
| L1, L2 | 7 Turns #22 AWG, 0.2" I.D. Ferrite Bead FERROXCUBE 56-590-65-3B as shown on L1 |
| FL1 | DC Supply Filter<br>2-1000 pF FT Capacitor<br>1-1.0 μF, 35 V Capacitor<br>1-Choke FERROXCUBE VK 200-20-4B |

Connectors are Type "N"
Board is Glass Teflon
3" x 5" x 0.060"
Mounting Plate is 3" x 5" x 0.75"

FIGURE 7 – 150 MHz to 450 MHz
TRIPLER USING 2N6256




| | | | |
|---|---|---|---|
| C1,C2,C3,C9,C10 | 1-7 pF ARCO 400 or Equivalent | L1 | 7 Turns 1/4" I.D. |
| C6,C7 | 1.5-20 pF ARCO 402 or Equivalent | L2 | 6-4 Turns 1/8" I.D. |
| C4,C5 | 470 pF ATC Type 100-B-420-m-ms | L3 | 0.68 μH Molded Choke |
| C8 | 1000 pF UNDERWOOD Type J-101 | L4 | 5 Turns 1/4" I.D. |
| C11 | 0.47 μF TANTALUM | L5 | 6 Turns 1/8" I.D. |
| C12,C14 | 470 pF Feedthru | L7 | 1 μH Molded Choke |
| C13 | 0.1 μF Ceramic | L8 | FERROXCUBE VK200-20/4B |
| R1 | 20 Ohm | L9 | Ferrite Bead, FERROXCUBE 56-590-65/3B |
| R2,R3 | 160 Ohm | | |

NOTE: All coils air core space wound with #20 AWG Wire, unless otherwise specified.

Figure 7 shows the 2N6256 in a 150 MHz to 450 MHz tripler circuit. This circuit will typically produce 85 mW at 450 MHz with 30 mW at 150 MHz input (4.5 dB gain). Collector efficiency is 25% and all unwanted harmonics are at least 30 dB down from the 450 MHz output level.

It is important that each emitter lead be bypassed separately with a good hi-quality capacitor. The emitter resistor is likewise split in two with one-half on each emitter lead.

The input network is a modified "TEE" consisting of C1, C2, and L1, which matches the 50 Ohm input to the transistor impedance at 150 mc; this is roughly 18-j20 Ohms. The combination of L2 and C3 form a 450 MHz idler to provide a base return for third harmonic current. L4, C6 and L5, C7 are 150 MHz and 300 MHz output idlers respectively. The output matching section is a pi network made up of L6, C9 and C10. All coils are air core space-wound (turns one wire diameter apart) with #20 AWG wire.

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF515

## The RF Line

0.75 W – 470 MHz

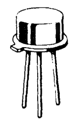
**HIGH FREQUENCY TRANSISTOR**

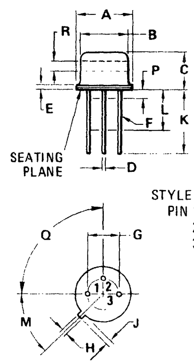
**NPN SILICON**

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for 12.5 Volt UHF large-signal amplifier applications required in industrial equipment

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 0.75 Watts
  Minimum Gain = 8.0 dB
  Efficiency = 50%
- S Parameter Data From 100 MHz to 1.0 GHz






STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

**CASE 79-02**
**TO-39**

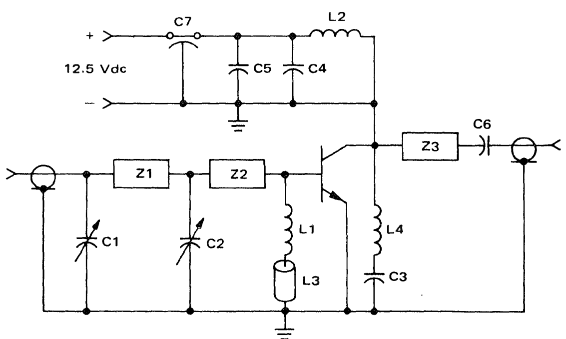
### MAXIMUM RATINGS

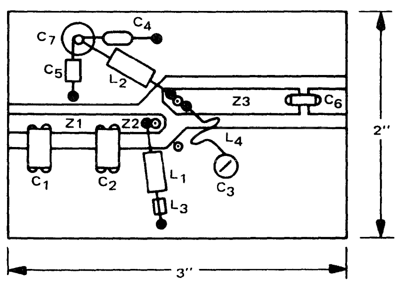
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 150 | mAdc |
| Total Device Dissipation @ $T_C = 25^{\circ}C$<br>Derate above $25^{\circ}C$ | $P_D$ | 2.5<br>14.3 | Watts<br>$mW/^{\circ}C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^{\circ}C$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 10 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | 60 | 150 | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 50 mAdc, $I_B$ = 5.0 mAdc) | $V_{CE(sat)}$ | – | – | 0.5 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc, f = 200 MHz) | $f_T$ | 1800 | 2000 | – | MHz |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.5 | 4.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 470 MHz) | $G_{PE}$ | 8.0 | 8.5 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 470 MHz) | $\eta$ | 50 | 70 | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 470 MHz) | $Z_{in}$ | – | 14+j4.0 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 470 MHz) | $Z_{out}$ | – | 28-j38 | – | Ohms |

FIGURE 1 – 470 MHz TEST CIRCUIT




C1,C2,C3 - 1.0-10 pF JOHANSON
C4 - 0.1 μF disc
C5 - 1.0 μF TANTULAM
C6 - 0.018 μF chip
C7 - 1000 pF Feedthru
L1,L2 - 0.15 μF Choke
L3 - Bead Ferrite
Z1,Z2 - 0.09" x 0.5" LINE, $Z_o$ = 100 Ω
Z3 - 0.18" x 1.0" LINE, $Z_o$ = 50 Ω

BOARD = 0.032" TEFLONGLASS, $\epsilon_R$ = 2.5

FIGURE 2 – OUTPUT POWER versus INPUT POWER

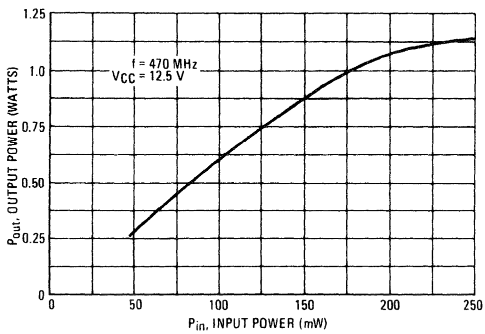



FIGURE 3 – CURRENT-GAIN – BANDWIDTH PRODUCT versus COLLECTOR CURRENT

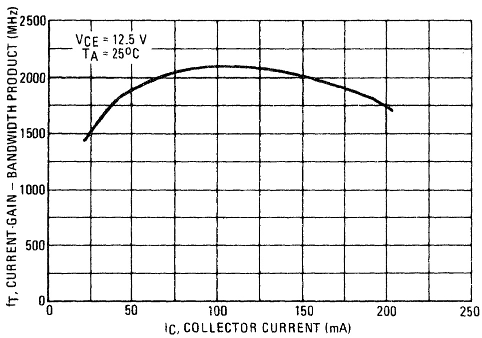



FIGURE 4 – OUTPUT CAPACITANCE versus COLLECTOR BASE VOLTAGE

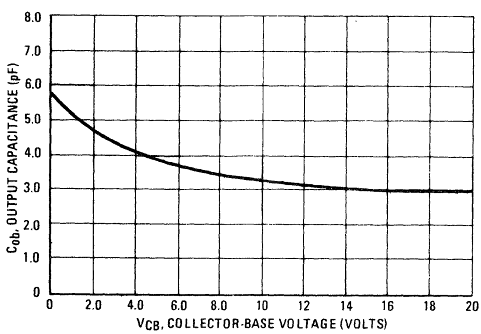


FIGURE 5 – $S_{11}$ and $S_{22}$ versus FREQUENCY

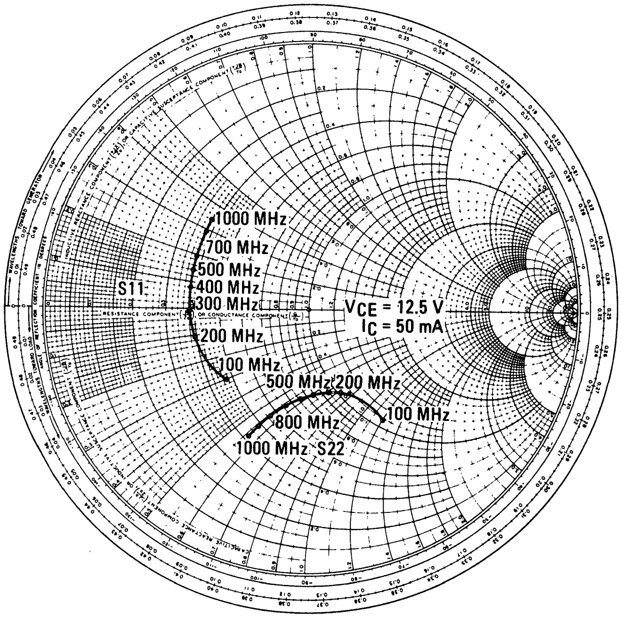



FIGURE 6 – $S_{12}$ versus FREQUENCY

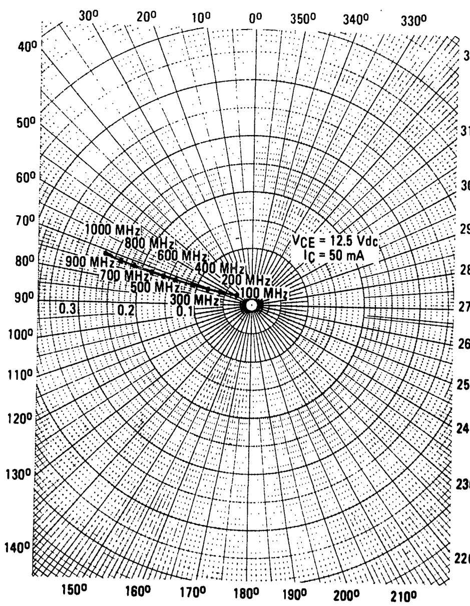
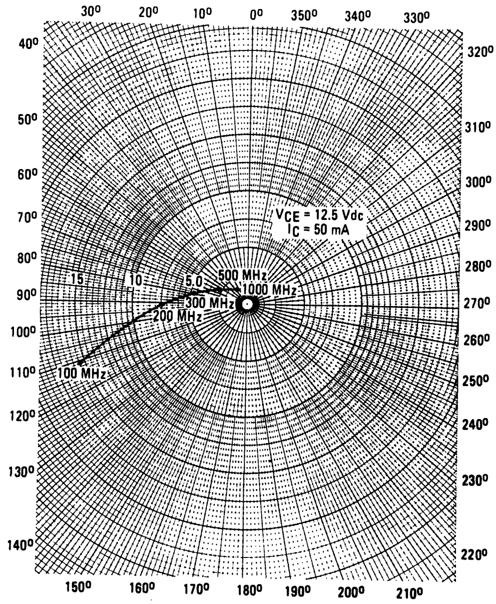



FIGURE 7 – $S_{21}$ versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF626
# MRF627

## The RF Line

0.5 W - 470 MHz

HIGH FREQUENCY
TRANSISTORS

NPN SILICON

## NPN SILICON HIGH FREQUENCY TRANSISTORS

. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating in the 407 to 512 MHz range. Ideally suited for requirements that specify optimum performance in a limited space.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 0.5 Watts
  Minimum Gain = 10 dB
  Efficiency = 60%

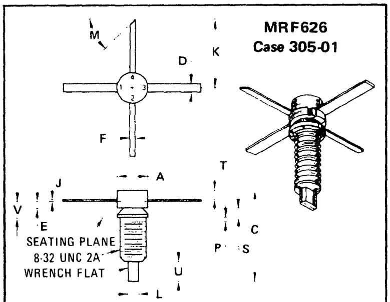
### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 30 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector-Current - Continuous | $I_C$ | 150 | mAdc |
| Total Device Dissipation @ $T_C = 25°C$<br>Derate Above 25°C | $P_D$ | 2.5<br>35 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200°C | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 28.5 | °C/W |

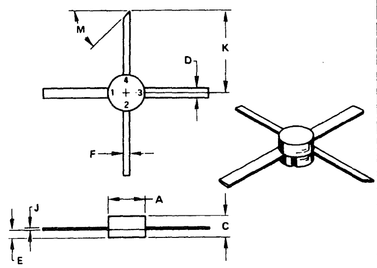
MRF626
Case 305-01




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 13.97 | 16.26 | 0.550 | 0.640 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| L | 1.40 | 1.65 | 0.055 | 0.065 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 1.40 | 1.65 | 0.055 | 0.065 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.79 | 3.81 | 0.110 | 0.150 |
| V | 2.41 | 2.92 | 0.095 | 0.115 |

MRF627
Case 305A-01



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 2.41 | 3.30 | 0.095 | 0.130 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 30 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 12 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 1.0 | mAdc |
| Emitter Cutoff Current ($V_{BE}$ = 3.5 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 15 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product | $f_T$ | | | | MHz |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 12.5 Vdc, f = 200 MHz) | | – | 2.5 | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 12.5 Vdc, f = 200 MHz) | | – | 2.7 | – | |
| ($I_C$ = 150 mAdc, $V_{CE}$ = 12.5 Vdc, f = 200 MHz) | | – | 2.6 | – | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | 3.5 | pF |
| Input Capacitance ($V_{BE}$ = 1.0 Vdc, $I_C$ = 0, f = 1.0 MHz) | $C_{ib}$ | – | 8.8 | – | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 470 MHz) | $G_{PE}$ | 10 | 12 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 470 MHz) | $\eta$ | – | 60 | – | % |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 470 MHz) | $Z_{in}$ | – | 6.0-j4.0 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, f = 470 MHz) | $Z_{out}$ | – | 45-j28 | – | Ohms |

FIGURE 1 — OUTPUT POWER versus INPUT POWER

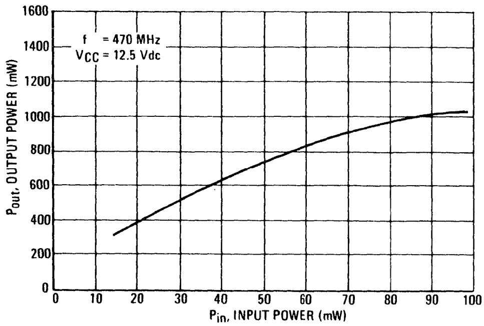



FIGURE 2 — OUTPUT CAPACITANCE versus COLLECTOR BASE VOLTAGE

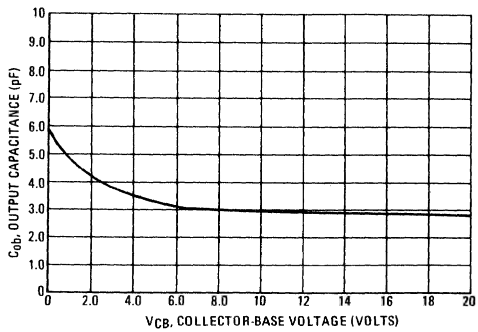
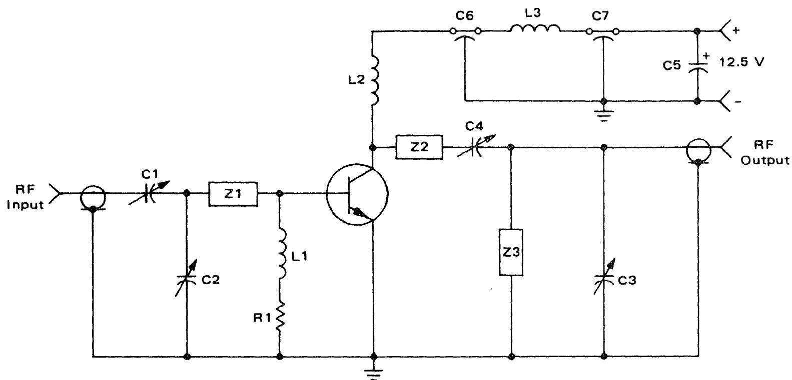


FIGURE 3 – 470 MHz TEST CIRCUIT SCHEMATIC




C1,C2 – 1.0-25 pF ARCO 421
C3,C4 – 1.0-25 pF ARCO 421
C5 – 1.0 μF, 35 V Capacitor
C6,C7 – 1000 pF Feedthru
L1,L2 – 7 Turns, #22 AWG, 0.2" I.D.
L3 – Choke FERROXCUBE VK 200-20-4B
R1 – 1 Ohm, 1/2 W Carbon

Z1 – Microstrip Line, 0.25" W x 1.75 " L
Z2 – Microstrip Line, 0.25" W x 2.00" L
Z3 – Microstrip Line, 0.50" W x 1.00" L
Board-Glass Teflon, 3" x 5" x 0.060"
Mounting Plate is 3" x 5" x 0.75"
Input/Output Connectors – Type N

FIGURE 4 – 470 MHz TEST CIRCUIT LAYOUT

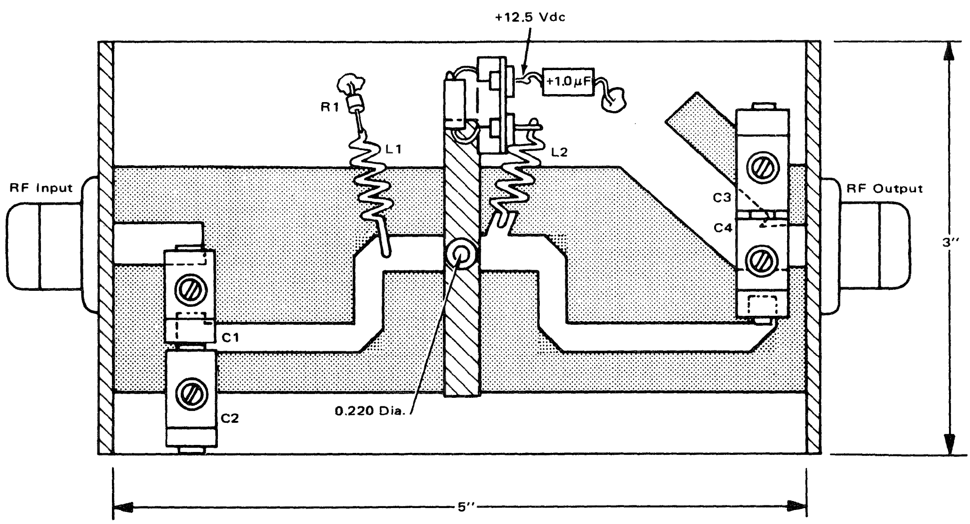


FIGURE 5 – TYPICAL $S_{11}$ and $S_{22}$ versus FREQUENCY

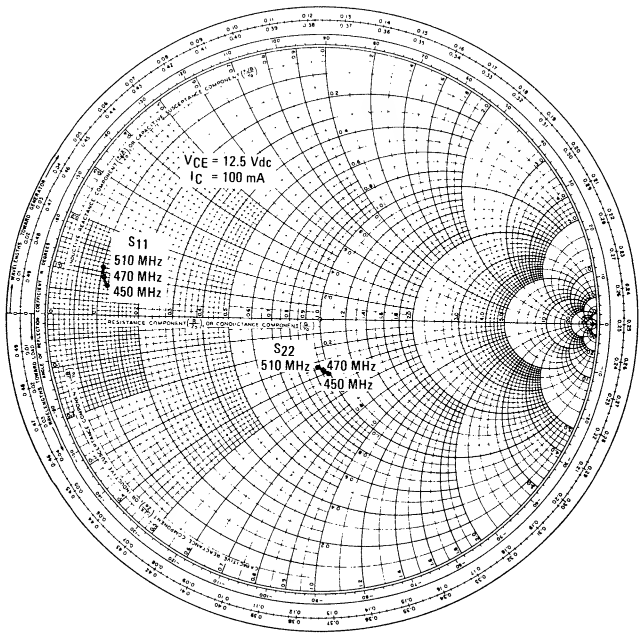



FIGURE 6 – TYPICAL $S_{12}$ versus FREQUENCY

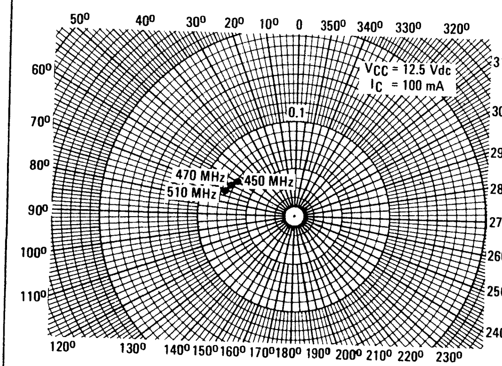
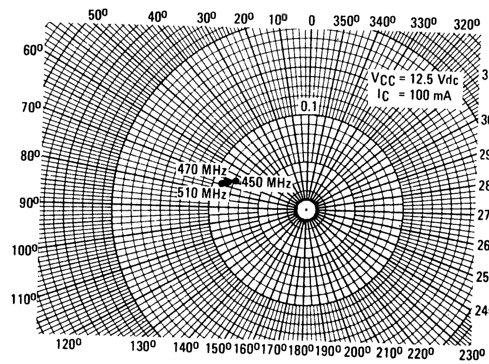



FIGURE 7 – TYPICAL $S_{21}$ versus FREQUENCY



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF628

## The RF Line

**0.5 W - 470 MHz**

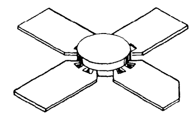
**RF POWER TRANSISTOR**

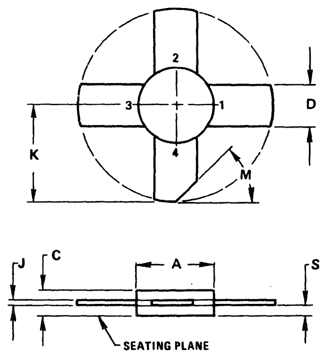
**NPN SILICON**

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 5.0 - 15 Volt, VHF/UHF large-signal Amplifier/Multiplier applications in military and mobile FM equipment.

- Specified 12.5 Volt, 470 MHz Characteristics
  Power Output = 0.5 Watts
  Minimum Gain = 10 dB
  Efficiency = 50%
- Characterized with Series Equivalent Large-Signal Impedance Parameters






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| C | 2.84 | 3.45 | 0.112 | 0.136 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| S | 1.40 | 1.65 | 0.055 | 0.065 |

CASE 249-05

### MAXIMUM RATINGS

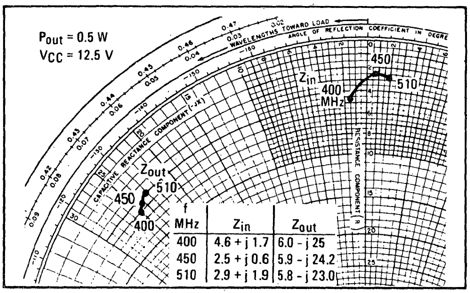
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 200 | mAdc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 3.0<br>17.2 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage (1) ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage (1) ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 20 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 2.0 | mAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_C$ = 0) | $I_{CBO}$ | – | – | 0.5 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 6.0 | 10 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, $I_C$(max) = 80 mAdc, f = 470 MHz) | $G_{PE}$ | 10 | – | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.5 W, $I_C$(max) = 80 mAdc, f = 470 MHz) | $\eta$ | 50 | – | – | % |

(1) Pulsed thru 25 mH inductor.

**FIGURE 1 – SERIES EQUIVALENT IMPEDANCE PARAMETERS**




| f MHz | $Z_{in}$ | $Z_{out}$ |
|---|---|---|
| 400 | 4.6 + j 1.7 | 6.0 - j 25 |
| 450 | 2.5 + j 0.6 | 5.9 - j 24.2 |
| 510 | 2.9 + j 1.9 | 5.8 - j 23.0 |

**FIGURE 2 – OUTPUT POWER versus INPUT POWER**

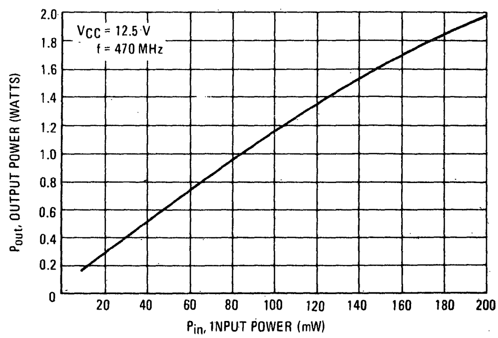


FIGURE 3 – OUTPUT POWER versus FREQUENCY

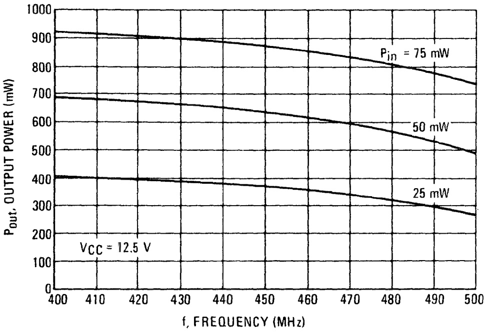



FIGURE 4 – OUTPUT POWER versus VOLTAGE

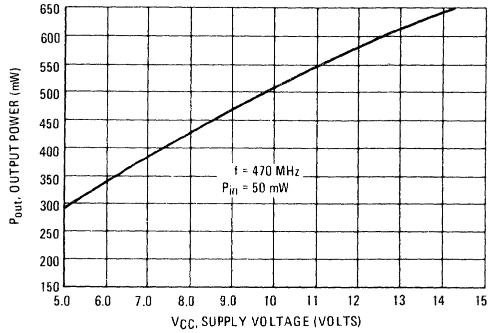



FIGURE 5 – 470 MHz TEST CIRCUIT

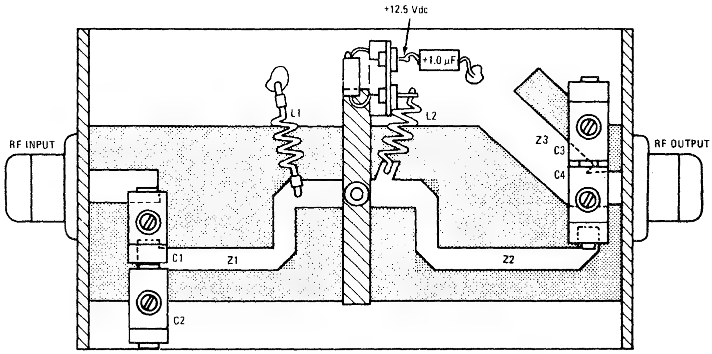
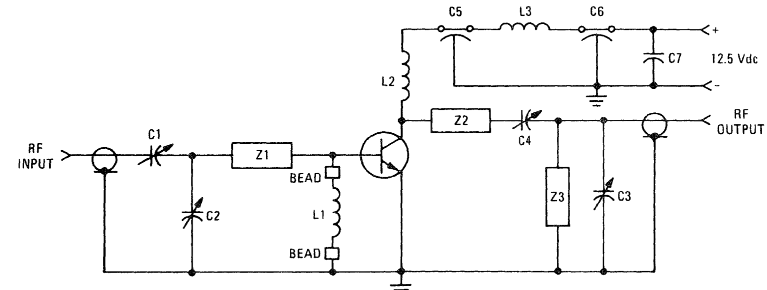



FIGURE 6 – 470 MHz TEST CIRCUIT SCHEMATIC




| | |
|---|---|
| C1,2,3,4 | 1.0-25 pF ARCO 421 OR EQUIVALENT |
| C5,6 | 1000 pF FEEDTHRU CAPACITOR |
| C7 | 1.0 µF, 35 V CAPACITOR |
| L1,2 | 7 TURNS #22 AWG, 0.2" I.D. FERRITE BEADS FERROXCUBE 56-590-65-3B AS SHOWN ON L1 |
| L3 | 1-CHOKE FERROXCUBE VK-200-20-4B |

BOARD-GLASS TEFLON, $\epsilon_R$ = 2.56, t = 0.062
MOUNTING PLATE – 3" x 5" x 0.060"
INPUT/OUTPUT CONNECTORS – TYPE N

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# MRF629

## The RF Line

### NPN SILICON RF POWER TRANSISTOR

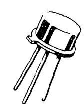
. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 2.0 Watts
  Minimum Gain = 8.0 dB
  Efficiency = 50%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Grounded Emitter TO-39 Package for High Gain and Excellent Heat Dissipation
- Replaces Medium-Power Stud Mounted Devices

**2 W - 470 MHz**

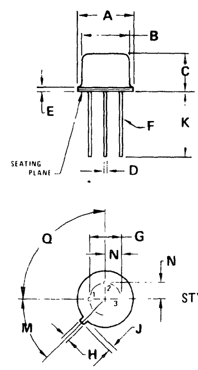
**RF POWER TRANSISTOR**

**NPN SILICON**



MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current - Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 5.0<br>28.5 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |




STYLE 5:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |

CASE 79-03

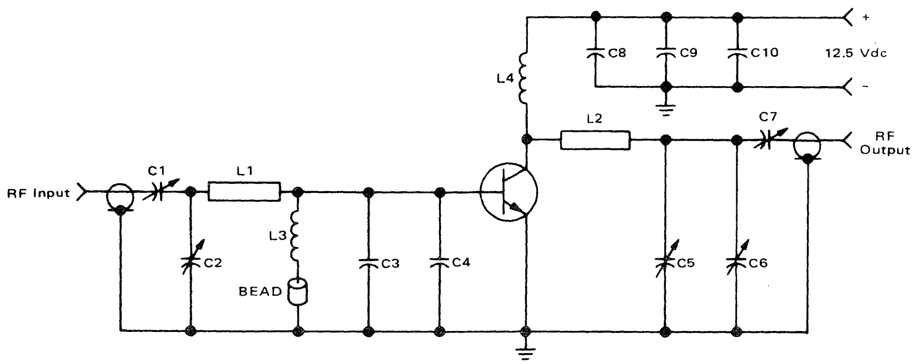
All JEDEC dimensions and notes apply.

**NOTE: The pin configuration on this version of the TO-39 package differs from the common isolated emitter type.**

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 15 | pF |
| **FUNCTIONAL TESTS (Figure 1)** | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 2.0 W, f = 470 MHz) | $G_{PE}$ | 8.0 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 2.0 W, f = 470 MHz) | $\eta$ | 50 | – | % |

**FIGURE 1 — 470 MHz TEST CIRCUIT SCHEMATIC**




C1,C5 — 1.5-20 pF, ARCO 402
C2,C6 — 1-10 pF, JOHANSON 2951
C3 — 15 pF, UNELCO
C4 — 25 pF, UNELCO
C7 — 8.0-60 pF, ARCO 404
C8 — 100 pF, UNELCO
C9 — 0.047 µF ERIE Disc Cap 100 V
C10 — 1.0 µF TANTALUM
L1,L2 — Copper Strap, 1" Length x 0.125" Width x 0.005" Thickness, x 2.54 cm
L3 — 3.3 µH Molded Choke
L4 — 0.15 µH Molded Choke
BEAD — FERROXCUBE 56-590-65-3B
INPUT/OUTPUT CONNECTORS — Type BNC

FIGURE 2 – OUTPUT POWER versus INPUT POWER

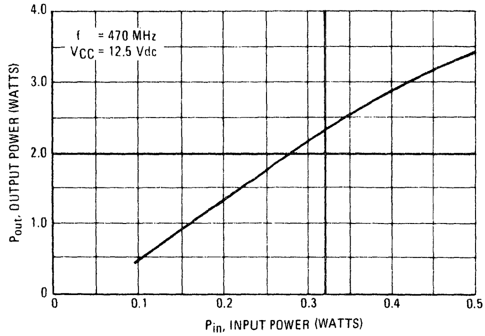



FIGURE 3 – OUTPUT POWER versus FREQUENCY

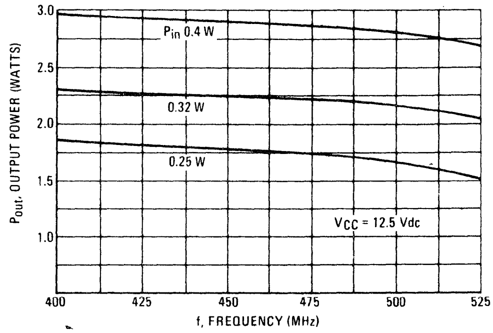



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

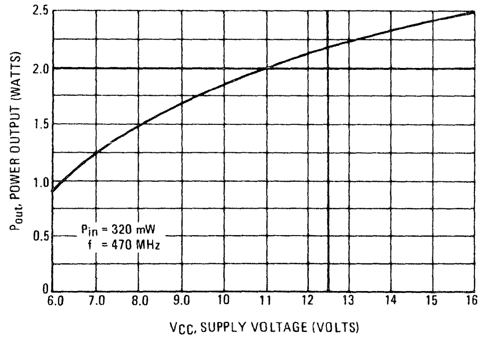
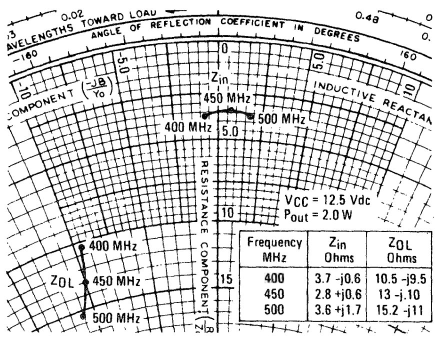



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| Frequency MHz | Zin Ohms | ZOL Ohms |
|---|---|---|
| 400 | 3.7 -j0.6 | 10.5 -j9.5 |
| 450 | 2.8 +j0.6 | 13 -j.10 |
| 500 | 3.6 +j1.7 | 15.2 -j11 |

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# MRF641

## The RF Line

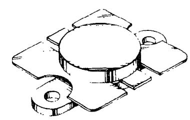
### NPN SILICON RF POWER TRANSISTOR

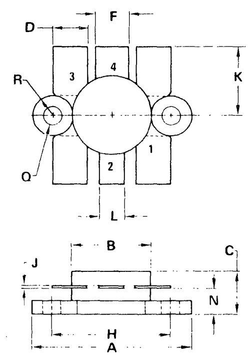
. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 15 Watts
  Minimum Gain = 7.0 dB
  Efficiency = 55%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch Stress at all Phase Angles with 20:1 VSWR @ 16-Volt High Line and 50% Overdrive.

15 W – 470 MHz

CONTROLLED Q
RF POWER
TRANSISTOR
NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | - | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak (10 seconds) | $I_C$ | 3.0<br>3.5 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 50<br>0.25 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 4.0 | $^oC/W$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 30 | 60 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 40 | 60 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 15 W, $I_C$ (MAX) = 2.2 Adc, f = 470 MHz) | $G_{pe}$ | 7.0 | 8.3 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, $I_C$ (MAX) = 3.6 Adc, f = 470 MHz) | $\eta$ | 55 | 60 | – | % |
| Output Mismatch Stress ($V_{CC}$ = 16 Vdc, $P_{in}$ = Note 1, f = 470 MHz, VSWR = 20:1, All Phase Angles) | $\psi$ * | No Degradation in Output Power | | | |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 470 MHz) | $Z_{in}$ | – | 1.5 + j 4.1 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 470 MHz) | $Z_{OL}$** | – | 3.4 + j 1.8 | – | Ohms |

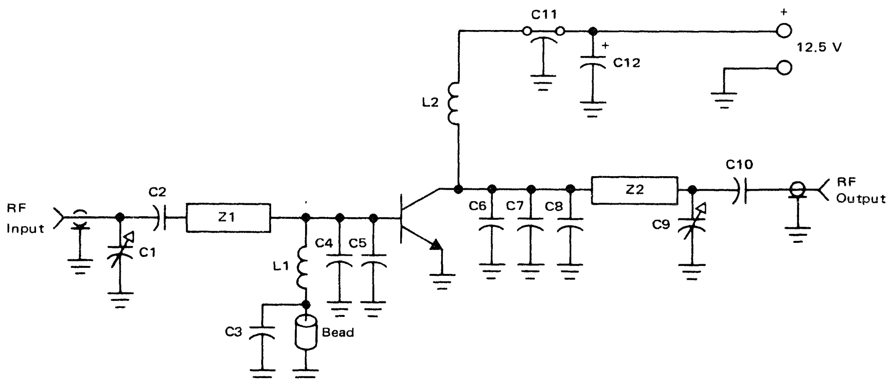
Notes:

1. $P_{in}$ = 150% of Drive Requirement for 25 W Output at 12.5 Vdc.

* $\psi$ = Mismatch stress factor—the electrical criterion established to verify the device resistance to load mismatch failure. The mismatch stress test is accomplished in the standard test fixture (Figure 1) terminated in a 20:1 minimum load mismatch at all phase angles.

** $Z_{OL}$ = Conjugate of the load impedance into which the device output operates at a given output power, $\eta_T$, and frequency.

**FIGURE 1 – TEST CIRCUIT SCHEMATIC**




C1 – 0.8-10 pF, Johanson C5201
C2, C3, C10 – 100 pF, UNELCO J101
C4, C5 – 25 pF, UNELCO J101
C6, C7 – 15 pF, UNELCO J101
C8 – 10 pF, UNELCO J101
C9 – 0.8-20 pF, Johanson 3906
C11 – 680 pF, Feedthru
C12 – 1.0 μF 35 V Tantalum

L1, L2 – 3 Turns #22 AWG 0.2 ID
Ferroxcube Bead 56-590-65-48
Z1 – Microstrip 1.0″ x 0.18″
Z2 – Microstrip 1.0″ x 0.25″
Board – 3″ x 5″ x 0.062″ Glass Teflon
Double Clad $\epsilon_R$ = 2.56
Heat Sink – 3″ x 5″ x 0.75″ Al Plate

FIGURE 2 – POWER OUTPUT versus POWER INPUT

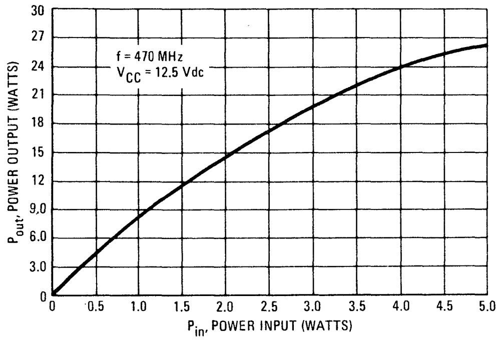



FIGURE 3 – POWER OUTPUT versus FREQUENCY

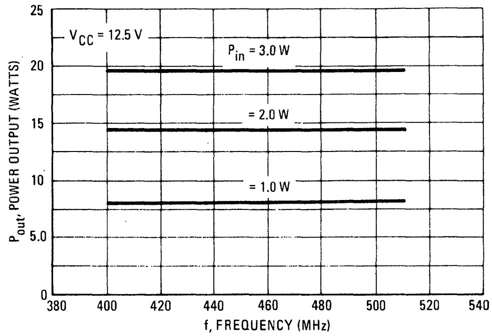



FIGURE 4 – POWER OUTPUT versus SUPPLY VOLTAGE

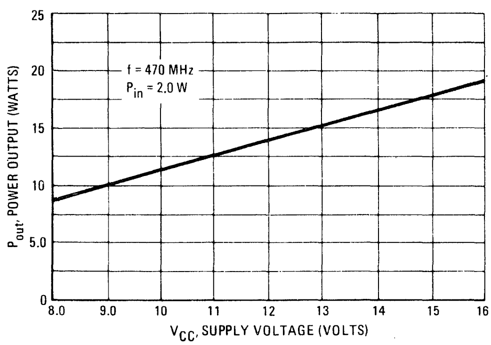



FIGURE 5 – POWER SATURATION PROFILE

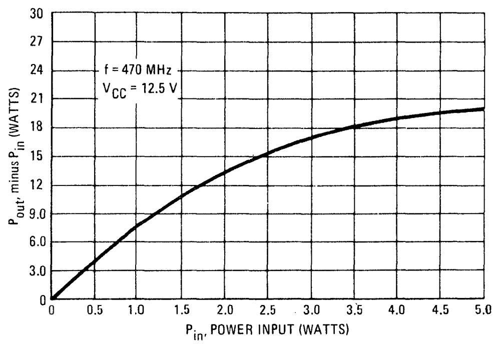
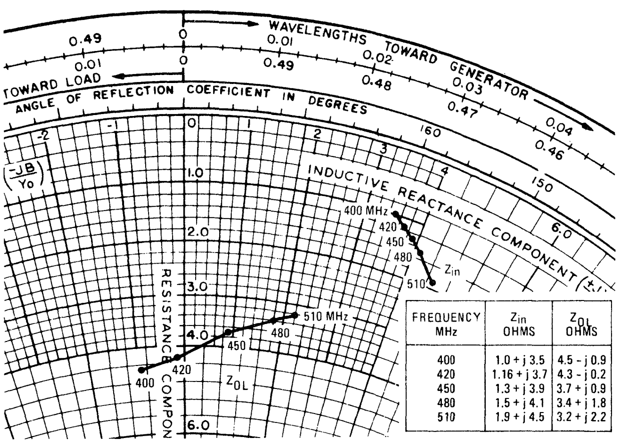
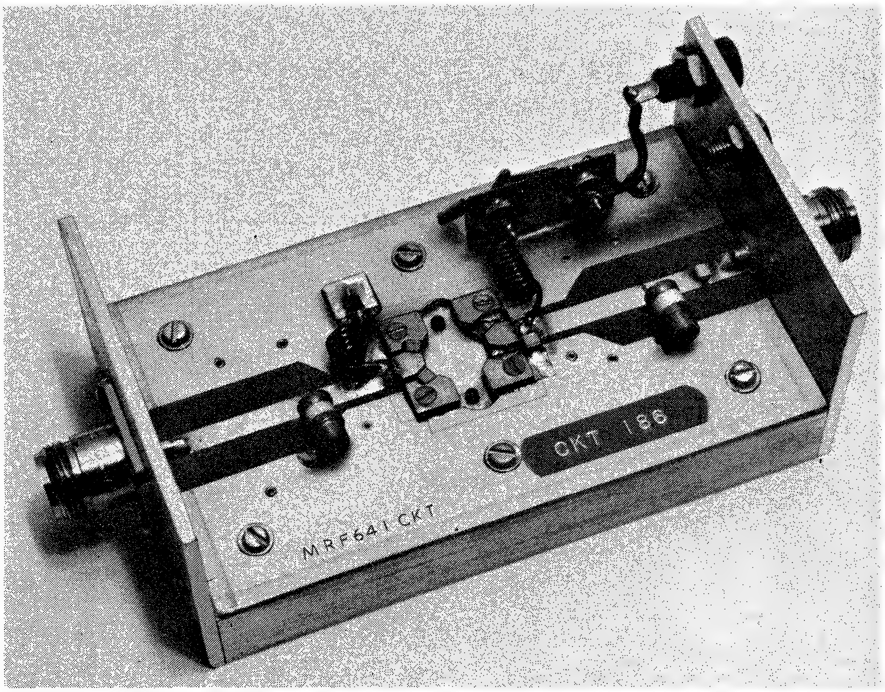


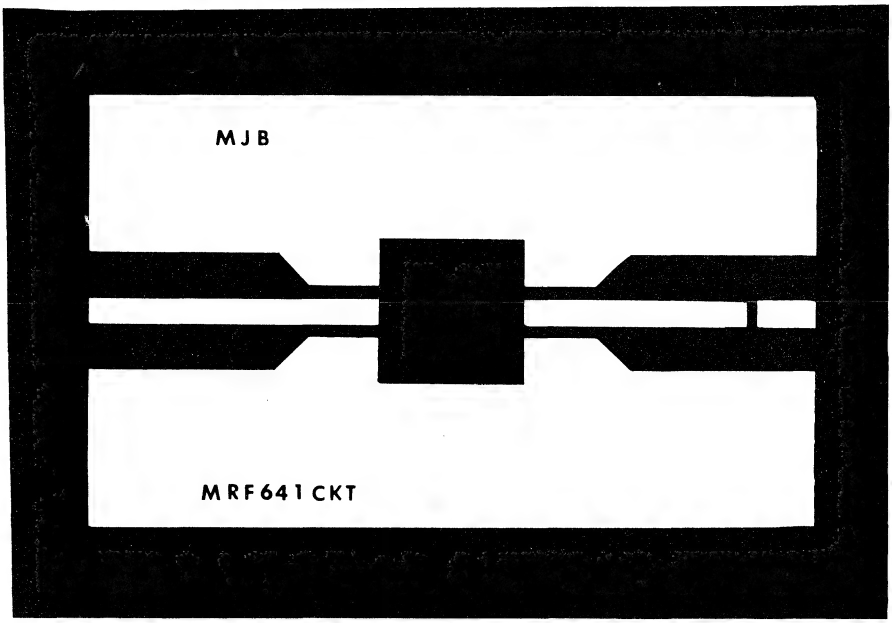

FIGURE 6 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| FREQUENCY MHz | $Z_{in}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 400 | 1.0 + j 3.5 | 4.5 - j 0.9 |
| 420 | 1.16 + j 3.7 | 4.3 - j 0.2 |
| 450 | 1.3 + j 3.9 | 3.7 + j 0.9 |
| 480 | 1.5 + j 4.1 | 3.4 + j 1.8 |
| 510 | 1.9 + j 4.5 | 3.2 + j 2.2 |




MRF641 TEST CIRCUIT



**MOTOROLA**
**Semiconductors**

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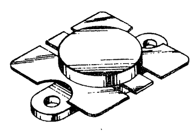
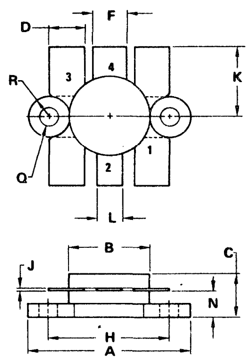
# MRF644

## The RF Line

25 W — 470 MHz

CONTROLLED Q
RF POWER
TRANSISTOR
NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 25 Watts
  Minimum Gain = 6.2 dB
  Efficiency = 60%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch Stress at all Phase Angles with 20:1 VSWR @ 16-Volt High Line and 50% Overdrive.

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak (10 seconds) | $I_C$ | 6.0<br>8.0 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 117<br>0.66 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

| | | | |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.5 | $^oC/W$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 4.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 40 | 70 | 100 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 90 | 85 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, $I_C$ (MAX) = 3.6 Adc, f = 470 MHz) | $G_{pe}$ | 6.2 | 7.0 | – | dB |
| Input Power ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 470 MHz) | $P_{in}$ | – | 5.0 | 6.0 | Watts |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, $I_C$ (MAX) = 3.6 Adc, f = 470 MHz) | $\eta$ | 55 | 60 | – | % |
| Output Mismatch Stress ($V_{CC}$ = 16 Vdc, $P_{in}$ = Note 1, f = 470 MHz, VSWR = 20:1, All Phase Angles) | $\psi$ * | No Degradation in Output Power | | | |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 470 MHz) | $Z_{in}$ | – | 1.2+j3.3 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 25 W, f = 470 MHz) | $Z_{OL}$** | – | 1.9 + j2.1 | – | Ohms |

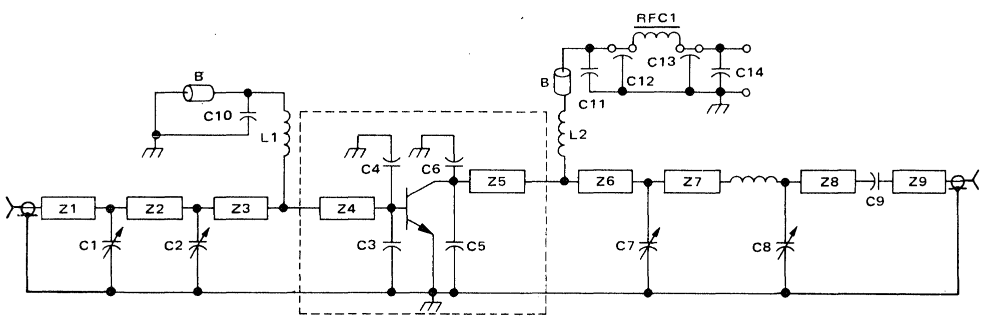
Notes:

1. $P_{in}$ = 150% of Drive Requirement for 25 W Output at 12.5 Vdc.

* $\psi$ = Mismatch stress factor—the electrical criterion established to verify the device resistance to load mismatch failure. The mismatch stress test is accomplished in the standard test fixture (Figure 1) terminated in a 20:1 minimum load mismatch at all phase angles.

** $Z_{OL}$ = Conjugate of the load impedance into which the device output operates at a given output power, $\eta_T$, and frequency.

**FIGURE 1 — TEST CIRCUIT SCHEMATIC**




| | | | | | |
|---|---|---|---|---|---|
| C1, C2, C7, C8 | 1–20 pF JOHANSON Variable | C12, C13 | 680 pF Feedthrough | Z3 | 0.20" x 0.20" Microstrip |
| C3 | 27 pF 100 mil ATC | L1 | 5" #22 AWG 0.100" ID | Z4, Z5 | 1/2" #18 AWG bent in a "V" shape 1/8" Wide |
| C4 | 30 pF 100 mil ATC | L2 | 5" #20 AWG 0.187" ID | | |
| C5, C6 | 33 pF 100 mil ATC | RFC1 | Ferroxcube VK200-20-4B | Z6 | 0.20" x 0.20" Microstrip |
| C9 | 250 pF 100 mil ATC | B | Ferroxcube Bead 56-590-65-3B | Z7 | 0.70" x 0.20" Microstrip |
| C10 | 100 pF UNELCO | Z1 | 0.25" x 0.20" Microstrip | Z8 | 0.33" x 0.20" Microstrip |
| C11, C14 | 1 μF 35 V TANTALUM | Z2 | 1.63" x 0.20" Microstrip | Z9 | 0.50" x 0.20" Microstrip |
| | | | | Board | 62.5 mil Glass Teflon, $\epsilon_R$ = 2.55 |

FIGURE 2 – POWER OUTPUT versus POWER INPUT

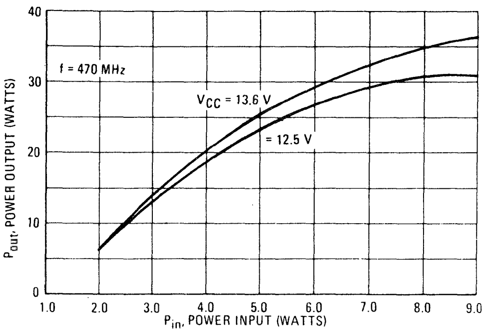



FIGURE 3 – POWER OUTPUT versus FREQUENCY

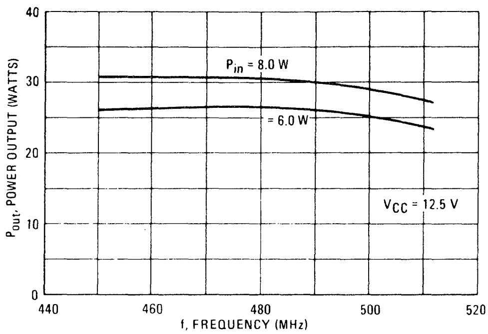



FIGURE 4 – POWER OUTPUT versus SUPPLY VOLTAGE

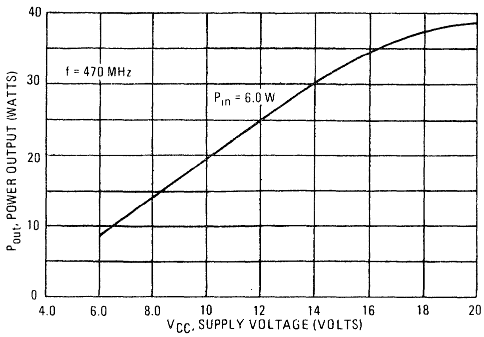



FIGURE 5 – POWER SATURATION PROFILE

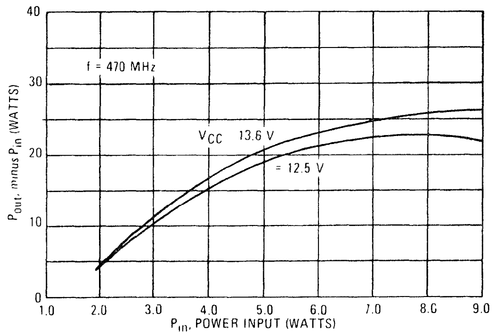



FIGURE 6 – DC SAFE OPERATING AREA

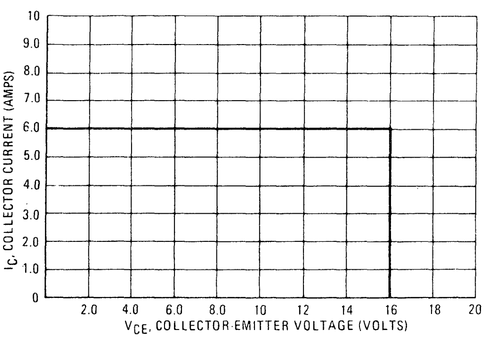
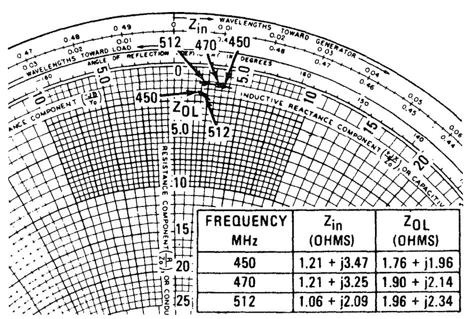
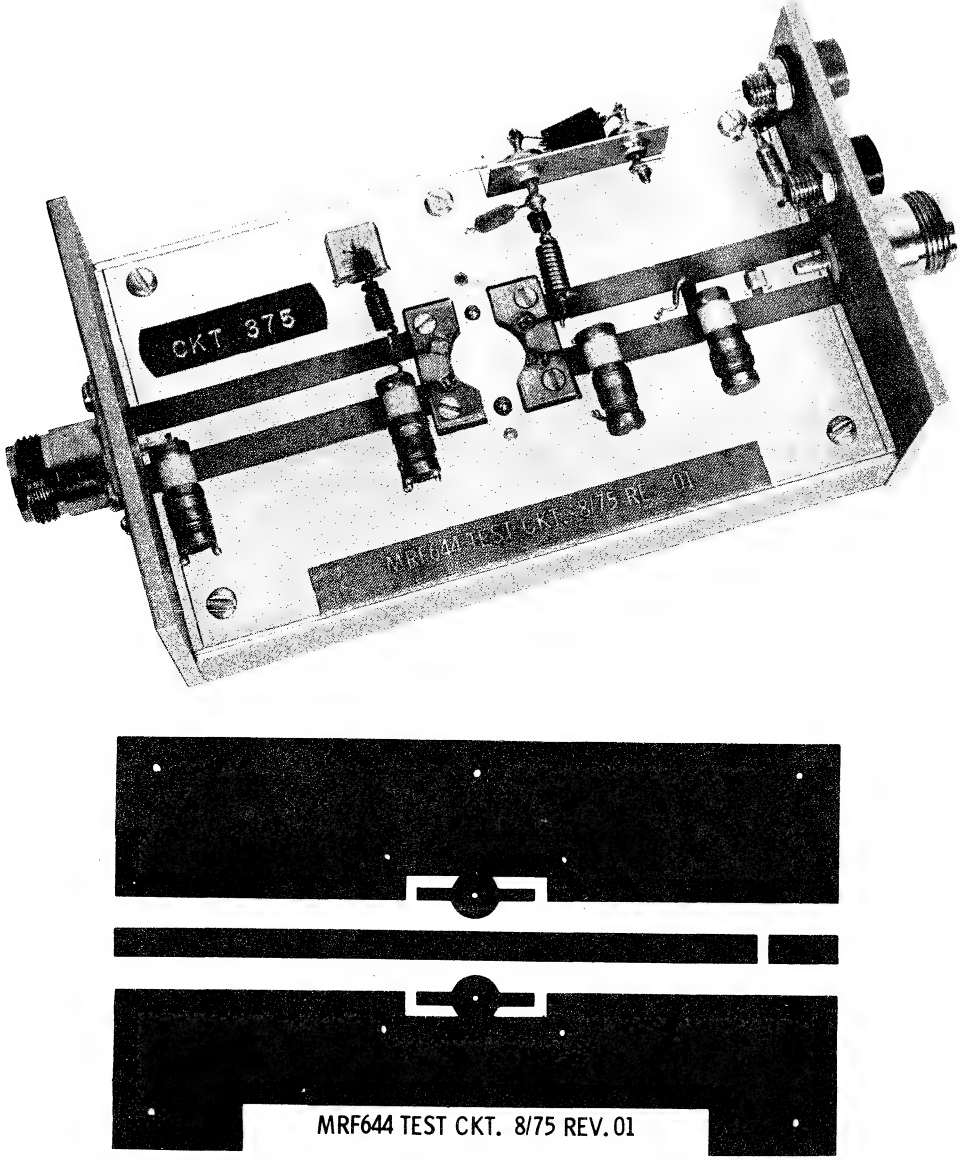



FIGURE 7 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| FREQUENCY MHz | $Z_{in}$ (OHMS) | $Z_{OL}$ (OHMS) |
|---|---|---|
| 450 | 1.21 + j3.47 | 1.76 + j1.96 |
| 470 | 1.21 + j3.25 | 1.90 + j2.14 |
| 512 | 1.06 + j2.09 | 1.96 + j2.34 |




TEST FIXTURE

MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF646

## The RF Line

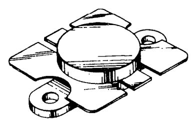
45 W – 470 MHz

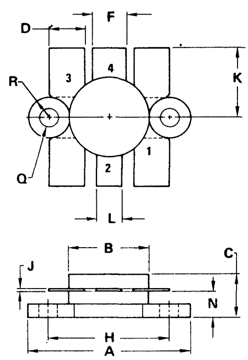
CONTROLLED Q

RF POWER

TRANSISTOR

NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE-ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics –
  Output Power = 45 Watts
  Minimum Gain = 4.8 dB
  Efficiency = 55%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch Stress at all Phase Angles with 20:1 VSWR @ 16-Volt High Line and 50% Overdrive.

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous<br>– Peak (10 seconds max) | $I_C$ | 8.0<br>10 | Adc |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate Above $25^oC$ | $P_D$ | 175<br>1.0 | Watts<br>$W/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 1.0 | $^oC/W$ |

## ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 20 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 25°C) | $I_{CES}$ | – | – | 10 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 4.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | 70 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 90 | 125 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 45 W, $I_C$(Max) = 5.8 Adc, f = 470 MHz) | $G_{pe}$ | 4.8 | 5.4 | – | dB |
| Input Power ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 45 W, f = 470 MHz) | $P_{in}$ | – | 13 | 15 | Watts |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 45 W, $I_C$ (Max) = 5.8 Adc, f = 470 MHz) | $\eta$ | 55 | 60 | – | % |
| Load Mismatch Stress ($V_{CC}$ = 16 Vdc, $P_{in}$ = Note 1, f = 470 MHz, VSWR = 20:1, All Phase Angles) | $\psi$* | No Degradation in Output Power | | | |
| Series Equivalent Input Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 45 W, f = 470 MHz) | $Z_{in}$ | – | 1.4 + j4.0 | – | Ohms |
| Series Equivalent Output Impedance ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 45 W, f = 470 MHz) | $Z_{OL}$** | – | 1.2 + j2.8 | – | Ohms |

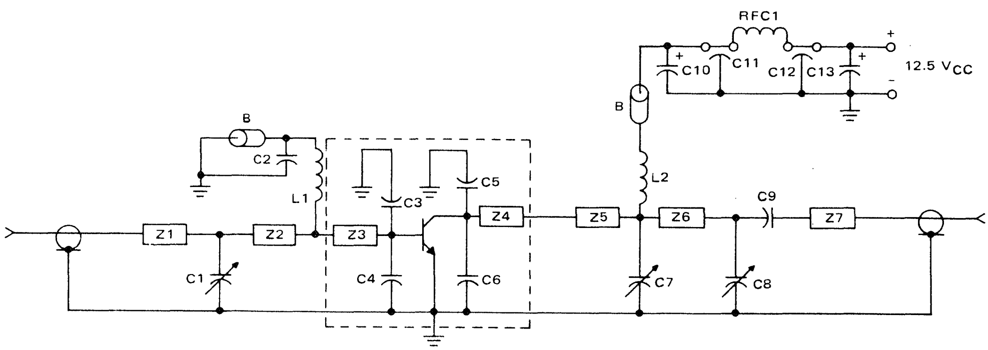
Notes:

1. $P_{in}$ = 150% of Drive Requirement for 45 W output @ 12.5 V.

* $\psi$ = Mismatch stress factor—the electrical criterion established to verify the device resistance to load mismatch failure. The mismatch stress test is accomplished in the standard test fixture (Figure 1) terminated in a 20:1 minimum load mismatch at all phase angles.

** $Z_{OL}$ = Conjugate of the load impedance into which the device output operates at a given output power, $\eta_T$, and frequency.

**FIGURE 1 – TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1, C8 | 1.0–20 pF JOHANSON | L2 | 5" # 20 AWG, 0.1" I.D. |
| C2 | 100 pF UNELCO | RFC1 | Ferroxcube VR200-20-4B |
| C3, C6 | 33 pF 100 mil ATC | Z1 | 0.525" x 0.190" Microstrip |
| C4 | 30 pF 100 mil ATC | Z2 | 1.475" x 0.190" Microstrip |
| C5 | 39 pF 100 mil ATC | Z3, Z4 | (0.2 x 0.2)/0.25 Alumina |
| C7 | 1–10 pF JOHANSON | Z5 | 0.190" x 0.190" Microstrip |
| C9 | 100 pF 100 mil ATC | Z6 | 1.150" x 0.190" Microstrip |
| C10, C13 | 1 μF 35 V TANTALUM | Z7 | 0.660" x 0.190" Microstrip |
| C11, C12 | 680 pF Feedthrough | Board | 62.5 mil Glass Teflon, |
| B | Ferroxcube Bead 56-590-65-3B | | $\epsilon_R$ = 2.55, λ = 0.0018 |
| L1 | 5" # 22 AWG, 0.1" I.D. | | |

FIGURE 2 – POWER OUTPUT versus POWER INPUT

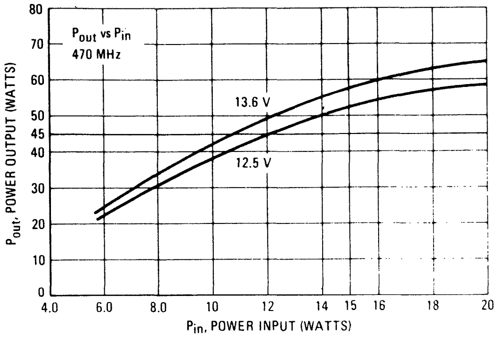



FIGURE 3 – POWER OUTPUT versus FREQUENCY

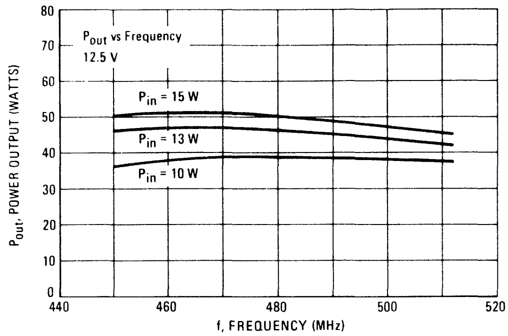



FIGURE 4 – POWER OUTPUT versus SUPPLY VOLTAGE

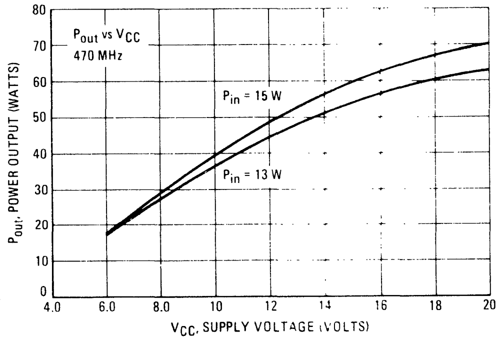



FIGURE 5 – POWER SATURATION PROFILE

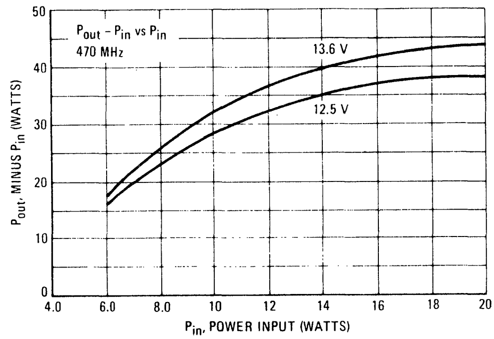



FIGURE 6 – DC SAFE OPERATING AREA

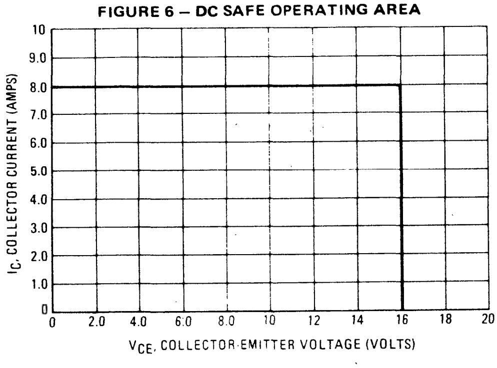
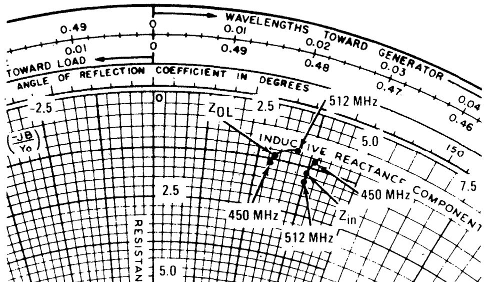
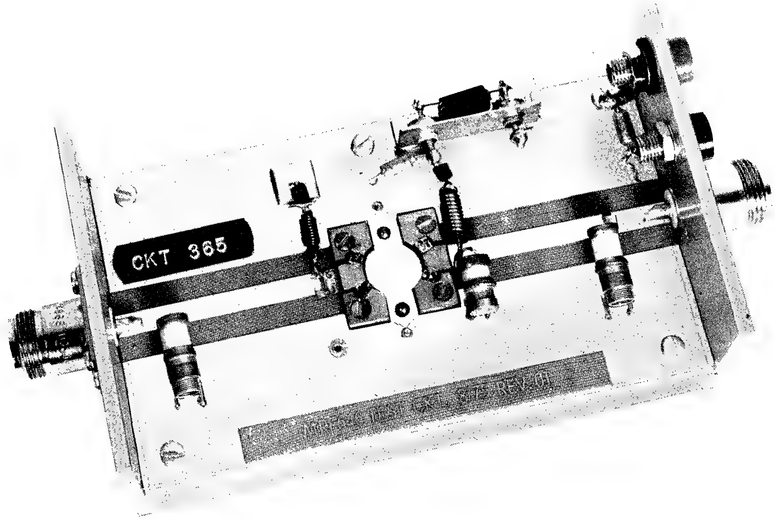


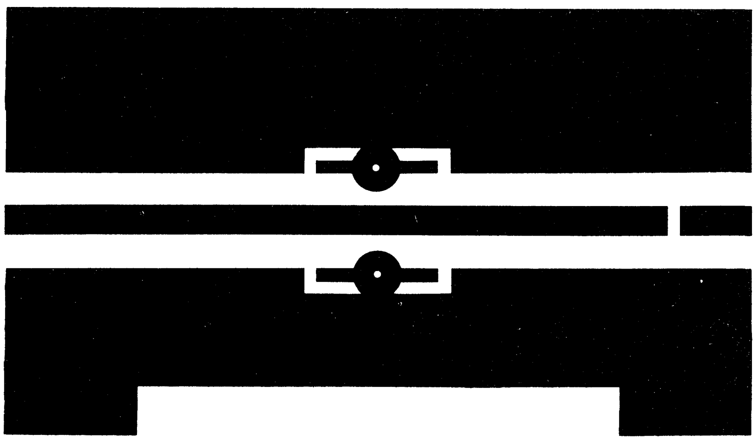

FIGURE 7 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE




| Frequency (MHz) | $Z_{in}$ (Ohms) | $Z_{OL}$** (Ohms) |
|---|---|---|
| 450 | 1.21 + j3.91 | 1.27 + j2.79 |
| 470 | 1.41 + j3.75 | 1.20 + j2.80 |
| 512 | 1.64 + j3.75 | 0.93 + j3.36 |




TEST CIRCUIT TEST FIXTURE



MRF646 TEST CIRCUIT 8/75 REV. 01

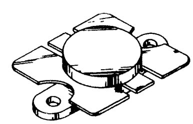
MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

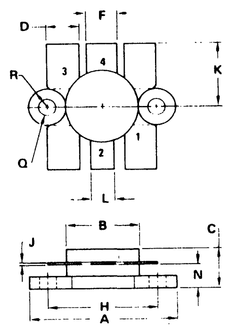
# MRF648

## The RF Line

60 W – 470 MHz

CONTROLLED Q
RF POWER
TRANSISTOR
NPN SILICON






STYLE 1.
PIN 1. EMITTER
2. COLLECTOR
3. EMITTER
4. BASE
FLANGE ISOLATED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 24.38 | 25.15 | 0.960 | 0.990 |
| B | 12.45 | 12.95 | 0.490 | 0.510 |
| C | 5.97 | 7.62 | 0.235 | 0.300 |
| D | 5.33 | 5.59 | 0.210 | 0.220 |
| F | 5.08 | 5.33 | 0.200 | 0.210 |
| H | 18.29 | 18.54 | 0.720 | 0.730 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 10.29 | – | 0.405 | – |
| L | 3.81 | 4.06 | 0.150 | 0.160 |
| N | 3.81 | 4.32 | 0.150 | 0.170 |
| Q | 2.92 | 3.30 | 0.115 | 0.130 |
| R | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 316-01

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, 470 MHz Characteristics —
  Output Power = 60 Watts
  Minimum Gain = 4.4 dB
  Efficiency = 55%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Built-In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch Stress at all Phase Angles with 20:1 VSWR @ 16-Volt High Line and 20% Overdrive

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 10 | Adc |
| – Peak (10 seconds) | | 13 | |
| Total Device Dissipation @ $T_C = 25°C$ | $P_D$ | 233 | Watts |
| Derate Above 25°C | | 1.33 | W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Value | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 0.75 | °C/W |

## ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted.)

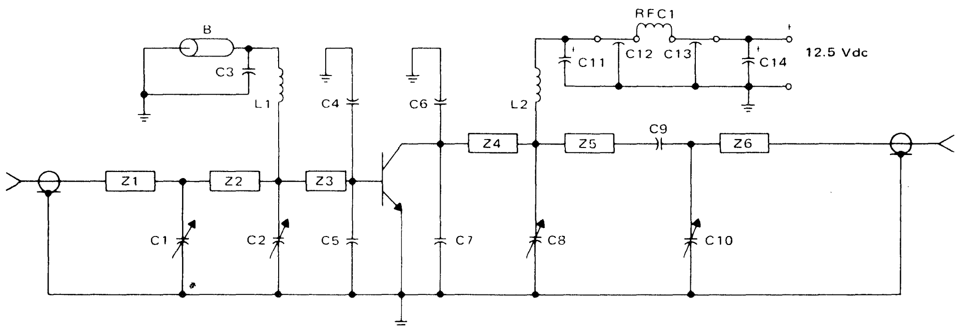
| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C = 50$ mAdc, $I_B = 0$) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C = 50$ mAdc, $V_{BE} = 0$) | $BV_{CES}$ | 36 | - | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E = 5.0$ mAdc, $I_C = 0$) | $BV_{EBO}$ | 4.0 | - | – | Vdc |
| Collector Cutoff Current ($V_{CE} = 15$ Vdc, $V_{BE} = 0$, $T_C = 25^oC$) | $I_{CES}$ | | – | 15 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C = 6.0$ Adc, $V_{CE} = 5.0$ Vdc) | $h_{FE}$ | 20 | 70 | 150 | - |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB} = 12.5$ Vdc, $I_E = 0$, f = 1.0 MHz) | $C_{ob}$ | | 130 | 150 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC} = 12.5$ Vdc, $P_{out} = 60$ W, f = 470 MHz) | $G_{pe}$ | 4.4 | 5.0 | – | dB |
| Input Power ($V_{CC} = 12.5$ Vdc, $P_{out} = 60$ W, f = 470 MHz) | $P_{in}$ | - | 19 | 22 | Watts |
| Collector Efficiency ($V_{CC} = 12.5$ Vdc, $P_{out} = 60$ W, f = 470 MHz) | $\eta$ | 55 | 65 | | % |
| Output Mismatch Stress ($V_{CC} = 16$ Vdc, $P_{in} = 26$ W, f = 470 MHz, VSWR = 20:1, All Phase Angles) | $\psi$ * | No Degradation in Output Power | | | |

Notes:

* $\psi$ Mismatch stress factor — the electrical criterion established to verify the device resistance to load mismatch failure. The mismatch stress test is accomplished in the standard test fixture (Figure 1) terminated in a 20:1 minimum load mismatch at all phase angles.

** $Z_{OL}$ Conjugate of the load impedance into which the device output operates at a given output power and frequency.

**FIGURE 1 — TEST CIRCUIT SCHEMATIC**




| | | | | | |
|---|---|---|---|---|---|
| C1, C2, C8, C10 | 1 20 pF Johanson | C12, C13 | 680 pF Feedthrough | Z2 | 1.39" X 0.190" Microstrip |
| C3 | 200 pF Unelco | B | Ferroxcube Bead 56 590 65 3B | Z3, Z4 | (0.2 X 0.2)/0.25 Alumina |
| C4, C5 | 33 pF 100mil ATC | L1 | 10 Turns #26 AWG 0.1" I.D. X 0.23" | Z5 | 1.30" X 0.190" Microstrip |
| C6, C7 | 36 pF 100mil ATC | L2 | 10 Turns #20 AWG 0.1" I.D. X 0.50" | Z6 | 0.330" X 0.190" Microstrip |
| C9 | 100 pF 100mil ATC | RFC1 | Ferroxcube VR200 19 4B | Board | 62.5mil Glass Teflon, $\epsilon_R = 2.55$, $\lambda$ - 0.0018, Dimension: 5.0" X 3.0" X 0.06" |
| C11, C14 | 1.0 $\mu$F 35 V Tantalum | Z1 | 0.46" X 0.190" Microstrip | | |

FIGURE 2 – POWER OUTPUT versus POWER INPUT

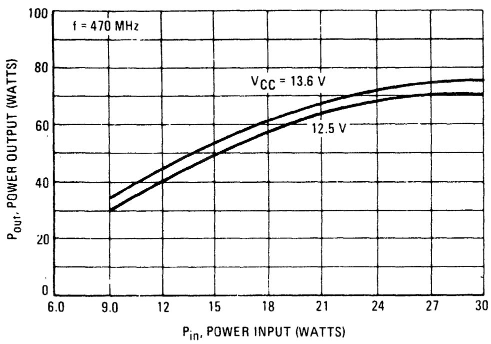



FIGURE 3 – POWER OUTPUT versus FREQUENCY

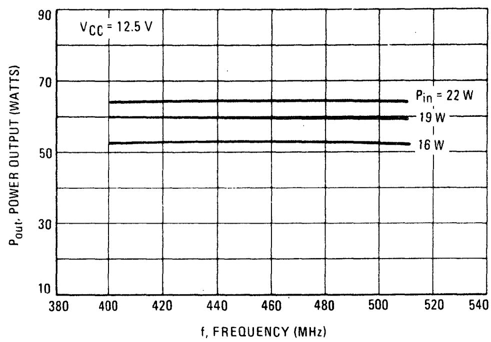



FIGURE 4 – POWER OUTPUT versus SUPPLY VOLTAGE

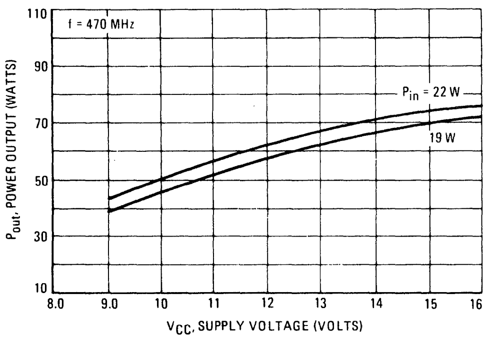



FIGURE 5 – POWER SATURATION PROFILE

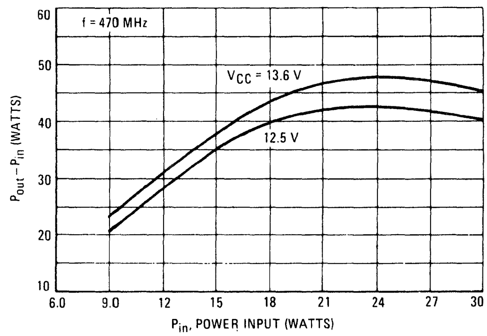
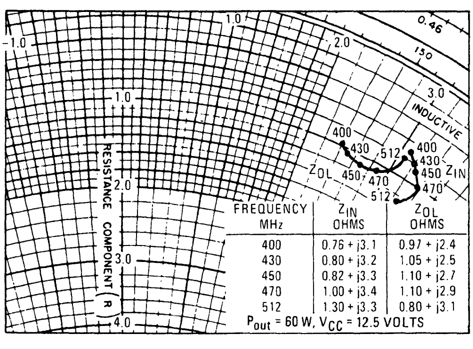
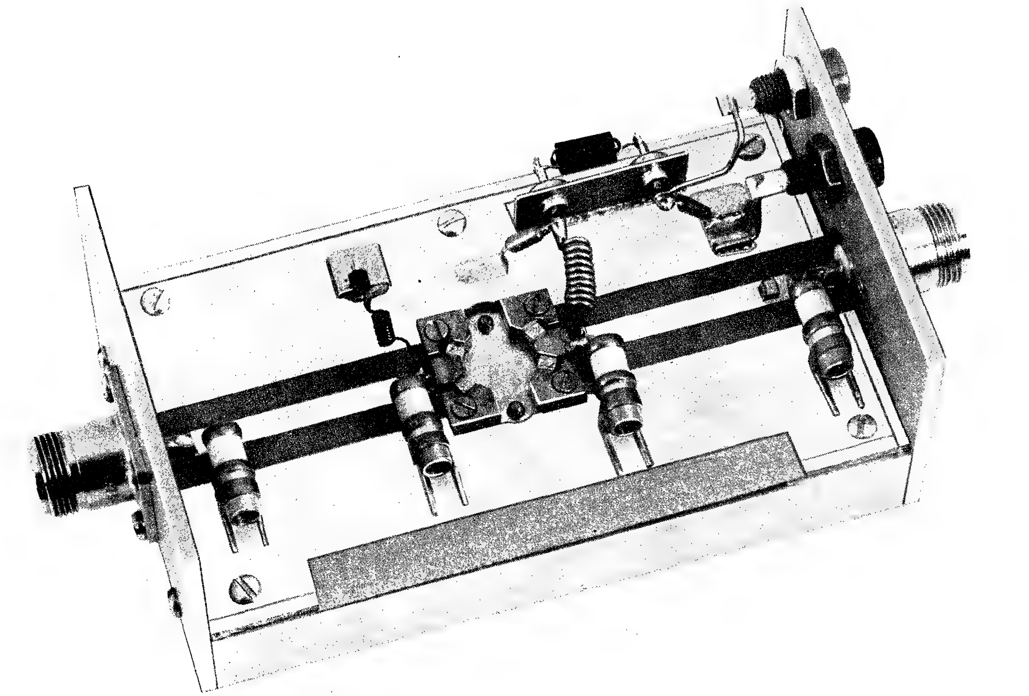



FIGURE 6 – SERIES EQUIVALENT INPUT-OUTPUT IMPEDANCE

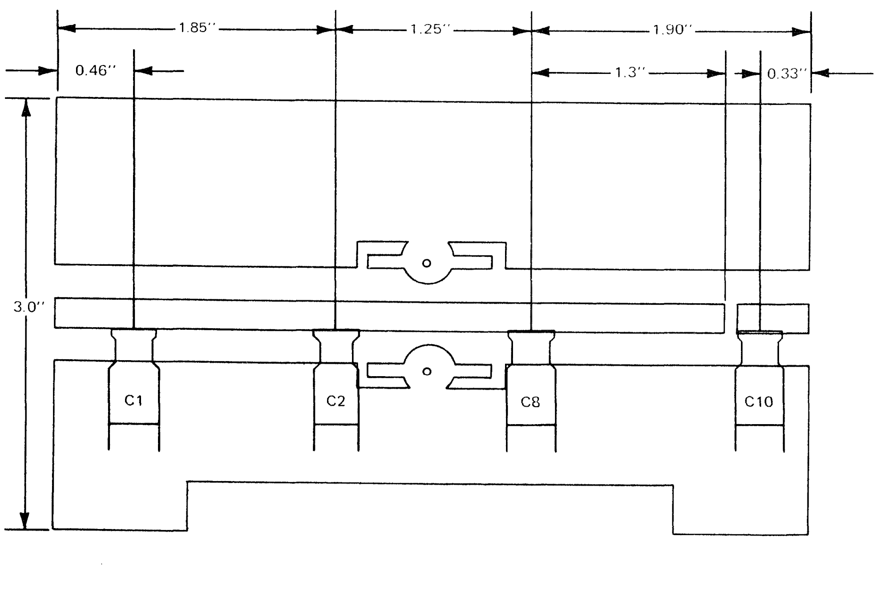



| FREQUENCY MHz | $Z_{IN}$ OHMS | $Z_{OL}$ OHMS |
|---|---|---|
| 400 | 0.76 + j3.1 | 0.97 + j2.4 |
| 430 | 0.80 + j3.2 | 1.05 + j2.5 |
| 450 | 0.82 + j3.3 | 1.10 + j2.7 |
| 470 | 1.00 + j3.4 | 1.10 + j2.9 |
| 512 | 1.30 + j3.3 | 0.80 + j3.1 |

$P_{out}$ = 60 W, $V_{CC}$ = 12.5 VOLTS

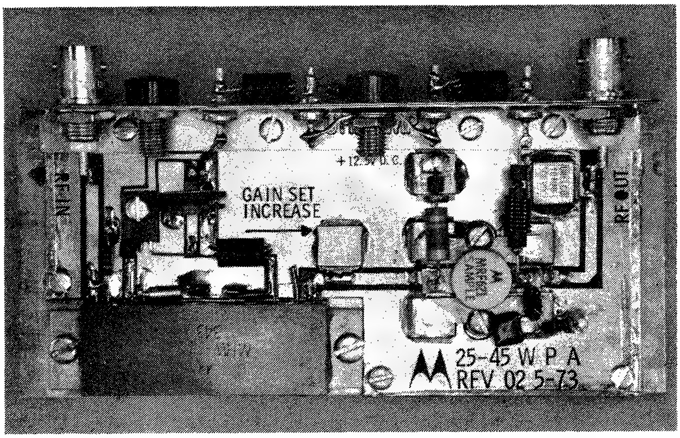


TEST CIRCUIT TEST FIXTURE



# "CQ", Modular Techniques Make 45 Watt UHF Amplifier Practical

*Prepared by:*
**Rich Potyka**
**Gordon McIntosh**




Today's two-way radio designer has a wide variety of RF, IF and audio ICs available to him for the simplification of both receiver and low-level transmitter circuits. The designer of high-level circuits is not quite so fortunate, although Motorola's UHF Power Modules and Controlled-Q transistors are close to being counterparts of the low-level ICs. By way of demonstration, one of each is used in this design for a practical 12.5 V, 45 W broadband UHF amplifier.

**UHF Power Modules**

The MHW709 (7.5 W) and the MHW710 (13 W) amplifiers are multistage, modular, power amplifiers for the 400- to 470-MHz communications band. They are 50 ohms in and out building blocks requiring a nominal 100 or 175 milliwatts of drive at 12.5 Vdc for their specified power outputs of 7.5 or 13 watts. For low-power transmitters of 5 to 10 watts, they may be used as the entire driver (power amplifier).

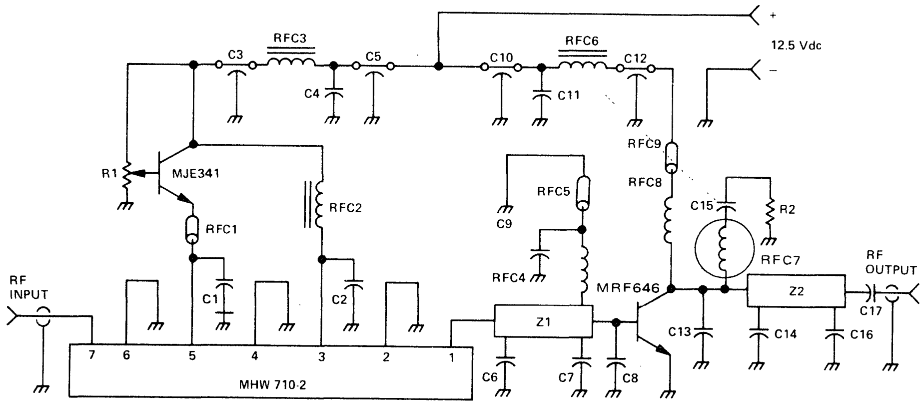
**MRF644, 646**

This family of "Controlled-Q" transistors operate from 25 to 45 watts output. Designed to follow either a power module or a line-up of broadband discrete drivers, they feature internal low-pass input matching networks and are rated to withstand load mismatches in excess of 20:1 without damage.

**A Practical Amplifier**

Our broadband demonstration amplifier uses the MHW710-2 and MRF646. Its power level is suitable for radios in the 35- to 40-watt class where losses in the output filter and antenna switch, along with production safety margin, approximate 5 to 7 watts. For lower power radios an MHW709-MRF644 (25 W) 644 amplifier could be built using the same techniques.

**Schematic Diagram/Parts List**
**UHF 45 W Amplifier**




R1  1 k CTS SF6106
R2  1/4 W 10% – 10Ω
RFC1, 5, 9  FERROXCUBE BEAD 56-590-65-3B
RFC2, 3, 6  FERROXCUBE VK200 20/4B
RFC4  5″ =22 AWG .095″ ID
RFC8  7 T NO. 20 ENAMELED 0.15″ ID CLOSE WOULD
RFC7  4 T NO. 24 ENAMELED ON AXIAL LEAD FORM 0.1 X 0.25″
C1, 4, 11  1 μF, 35 V TANTALUM
C2, 15  0.1 μF, 100 V ERIE REDCAP

C3, 5, 10, 12  680 pF ALLEN BRADLEY FEEDTHROUGH
C6  pF UNELCO – 5 pF
C7  25 pF UNELCO
C8, C13  14 UNELCO – 30 pF
C16  10 pF UNELCO
C17  0.18 μF, CHIP CAP, VITROMON (2 EACH)
C9  100 pF UNELCO

BOARD: G10 $\epsilon_r \approx 5$, t = 62 MILS
2-SIDED 2-OZ Cu CLAD

## Construction

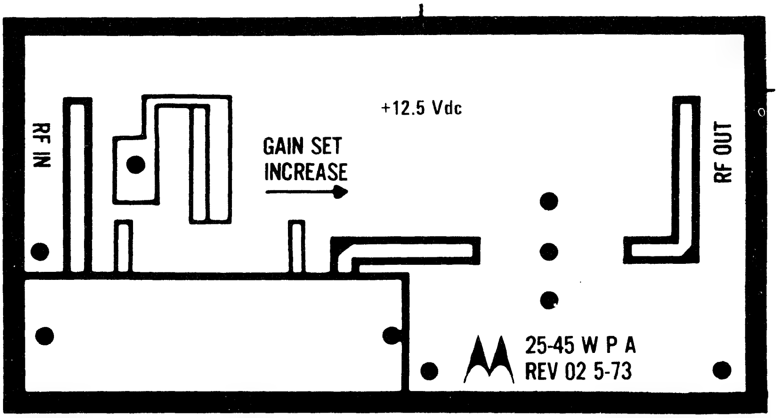
The majority of the rf and dc circuitry is printed on a double-sided,.2-ounce copper, 62-mil G10 circuit board. A full scale (1:1) reproduction of the circuit-side photomaster is shown. The ground side of the board is solid foil. Commercial grade G10 ($\epsilon_r \approx 5$) material provides a good compromise between cost and rf circuit losses. By using the two-sided board, microstrip style distributed inductors can be printed which are very consistent and independent of chassis or heatsink grounds. Multiple rivets, marked "••" on the layout, are used to connect the circuit-side ground pads with the bottom groundplane. The dc distribution circuit is mounted on a copper angle bar. For demonstration purposes, the input and output connectors, as well as the dc connectors, are mounted on this bar.

## DC Distribution

The 25 dB of gain available at 470 MHz necessitates proper RF isolation between the active devices for stable operation. A combination of low-inductance feedthrough capacitors and ferrite chokes assures this. These components also provide decoupling of the range from 1 to 20 MHz where parasitic oscillations are likely to occur. To set the power output, a dc control transistor and low-current pot are connected to the control pin of the MHW710. This control gives a smooth, stable, 6-dB gain adjustment and also provides a convenient input point for AGC or SWR shut-down circuits.

## RF Circuits

Input to the MHW710 is nominally 50 ohms.




PC LAYOUT

The interstage network consists of a 3-element, low-pass filter. This circuit completes the internal transformation of the MRF646 "CQ" input network to 50 ohms and, in addition, develops a small amount of frequency compensation to flatten the overall amplifier response.

The output matching circuit consists of a 4-element, low-pass network. The first series L is made up of the transistor lead inductance. Discrete shunt capacitors and a printed distributed inductor (microstrip line) make up the remaining elements. Capacitor C16 may be made adjustable to compensate for loads other than 50 ohms such as output filters or antenna mismatch.

UNELCO capacitors are used throughout as shunt tuning elements on the basis of performance, cost and ease of use. ATC ceramic chip capacitors work well also, but their cost is several times higher than the UNELCO types. Distributed capacitance made up of large areas of line may be used, however, the area that would be required with this type of board material is prohibitively large and the capacitive value less consistent than that of the recommended discrete capacitor types.

A selective, low-frequency loading network (R2, RFC7, C15) shunts the collector of the MRF646 to damp oscillation at frequencies less than 50 MHz during high SWR (6:1) load mismatches. Similarly, the base decoupling network selectively provides a high Q return at 450 MHz, and a lossy load below approximately 50 MHz.

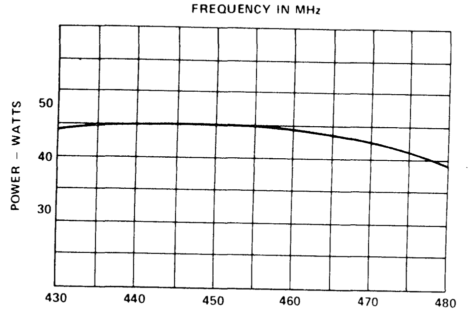



**Figure 1**

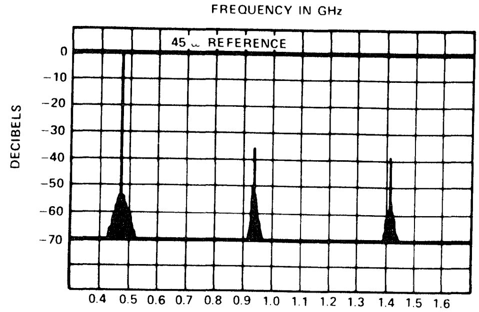



**Figure 2**

### Performance

Figure 1 shows the swept Power Out–vs–Frequency for a 175-mW drive (control fixed for 45 W out at 470 MHz). Figure 2 is the output spectrum for a 470-MHz CW carrier. All harmonics are greater than 40 dB below the carrier level. No noncoherent spurious output exists for any condition of drive or supply voltage.

### Move Over, ICs

As our design demonstrates, the MHW709-710 and the MRF644, 646 products are truly practical high-power building blocks for the UHF radio designer. They enable him to select the appropriate combination of module and "Controlled-Q" transistor, and build simple, low-cost and easily reproducible amplifiers providing up to 45 W of broadband power in the 400- to 480-MHz communications band.

**MHW710-2/MRF646 Amplifier**
**Pin – 175 mw**

| Adjusted for 45 W @ 470 MHz | | | | Adjust for Max $P_{out}$ | | | |
|---|---|---|---|---|---|---|---|
| Freq MHz | $P_{out}$ W | Ic a | $\eta$ % | Freq MHz | $P_{out}$ W | Ic a | $\eta$ % |
| 430 | 48.0 | 10.5 | 37 | 450 | 60.0 | 10.8 | 44 |
| 440 | 50.0 | 9.7 | 41 | 460 | 56.0 | 9.7 | 46 |
| 450 | 49.5 | 9.0 | 44 | 470 | 53.0 | 9.2 | 46 |
| 460 | 48.0 | 8.35 | 46 | | | | |
| 470 | 45.0 | 7.75 | 46 | | | | |
| 480 | 39.0 | 6.85 | 46 | | | | |

| Harmonics 470 MHz 45 W output | |
|---|---|
| 2nd | 45 dB |
| 3rd | 53 dB |
| 4th | 72 dB |

**References:**
MHW710, MHW709, MRF646 Data Sheets
AN-555 Mounting Techniques

# ONE CQ TRANSISTOR — TWO 45 W UHF AMPLIFIERS

*Prepared by:*
**Gordon McIntosh**

This Engineering Bulletin describes the design and assembly techniques necessary to produce a 12.5 V, 45 W, UHF amplifier. Because different requirements for bandwidth exist at this power level and frequency, two different design schemes are discussed. The first is a low cost amplifier using low cost UNELCO**-type capacitors for applications where wide bandwidth is not necessary. (Figure 1a.) The second approach uses high Q, low parasitic inductance, ceramic chip capacitors to achieve wider bandwidth. (Figure 1b.)

The amplifier design is based upon Motorola's newly introduced MRF646, a 12.5 V, internally matched *CQ transistor (Figure 2). The MRF646 features controlled impedance and ruggedized performance guaranteed by 100% testing for $G_{pe}$, $\eta_c$, input VSWR and burnout in a fix tuned circuit. Ruggedization of the MRF646 has been accomplished by a computer designed thermal layout of the die, resistor ballasting of each emitter site and careful control of die to heatsink thermal resistance. Burnout testing is done at 16 $V_{CC}$ and 150% overdrive. (150% over typical drive necessary to make 45 W $P_{out}$.)

Internal matching[1] is a transforming network built inside the transistor package necessary to raise the low base impedance (0.25 - j0.25Ω) to a level usable by circuit designers. (Figure 2.) Comprised of wire bonds and a single MOS capacitor, this network is the first three elements in a six element low pass transforming filter from chip base impedance to fifty ohms and was designed to give optimum performance over the 450-512 MHz band. The device package also contains one output network element which is the collector series transmission line ($Z_S$). Careful control of input and output impedance is made possible by precision assembly techniques which include accurate die placement under

*CQ is a trademark of Motorola, Inc.
**UNELCO is a trademark of Underwood Electric Div., Standex Electronics

[1] EB-19 Controlled Q RF Technology

FIGURE 1(a).

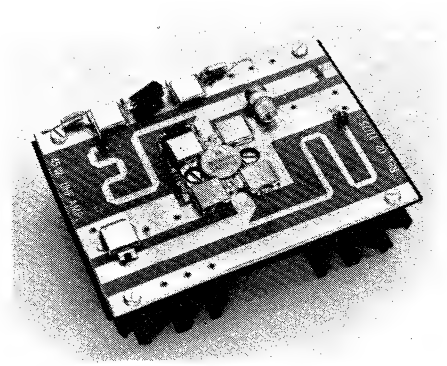
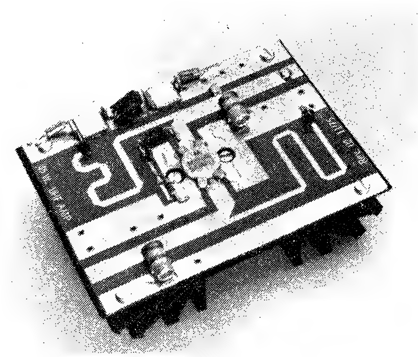


FIGURE 1(b).



reticule eyepiece and utilization of automated wire bonders. Typical impedances are presented in Table 1, Figure 3.

Performance goals for the amplifiers were as follows:

1. The low cost amplifier will operate over the 450-470 MHz commercial band and the improved version will operate from 450-512 MHz.
2. Amplifiers will deliver 45 W into fifty ohms with collector efficiency greater than 50%.
3. All harmonics are to be 30 dB below 45 W.
4. Amplifiers will not oscillate when output is terminated with a 6:1 load mismatch at any phase angle and no spurious output will result from any combination of reduced drive and supply voltage.

Design considerations to meet these requirements include initial "paper" design, component selection on the basis of theoretical design, and the printed circuit board layout. The "paper" design includes taking the impedances data published on the MRF646 data sheet, selecting the correct network to accomplish the desired transformations and using either computer optimization, Smith Charts, or impedance matching tables[2] to arrive at idealized component values.

In the design presented (Figure 4), three element low pass filter networks were selected for both input and output. The input network is an extension of the internal matching, completing the six element transforming network from device base impedance to 50 ohms. The output network completes the 4 element network from device collector to fifty ohms and presents an impedance to the collector ($Z_{OL}$*) which allows the transistor to operate at the desired output power and efficiency over a given bandwidth. The networks for the input and output are similar and are comprised of a shunt capacitor, a series transmission line and a shunt capacitor. The transmission line is used instead of an inductor because it may be printed, thus reducing costs and improving circuit consistency. Also, the transmission line may be used to transform the real part of the impedance whereas the inductor cannot.

[2]George L. Matthaei, "Tables of Chefyshev Impedance-Transforming Networks of Low-pass Filter Form," Proceedings of the IRE, Vol. 52, p. 939 (August, 1964).

Rule of thumb design aids may be of use to start an initial design. Using a Smith Chart with normalized admittance and impedance coordinates (Figure 3), we begin by defining the transistor as the load and the fifty ohm point as the source. All impedances are then normalized to the characteristic impedance of the series transmission lines used in the matching network (Z normalized = $\bar{Z}$ = $Z/Z_O$). In the design example presented (Figure 3), we will transform the input impedance at midband (470 MHz) to 50 ohms. Starting at the load (transistor), $C_k$ will transform the impedance along the circle of constant conductance, $\bar{a}_1 = \frac{Z_O}{X_2}$, until the real axis is reached.

$Z_1 = X_1 + jY_1$ = Transistor input impedance

$X_2 = \dfrac{X_1^2 + Y_1^2}{X_1}$ = Transformed real impedance at capacitor $C_k$

$C_k$ is the parallel combination of $C_2$ and $C_3$ in Figure 4.

The normalized capacitive reactance, $\bar{X}_{ck}$, necessary to accomplish this transform, may be read from the Smith Chart by reading the normalized susceptance at the transistor and taking its inverse. An exact expression will aid in compressed regions of the Smith Chart.

$$X_{ck} = \frac{X_1^2 + Y_1^2}{Y_1}\ \Omega$$

$$C_k = \frac{Y_1}{(\omega)(X_1^2 + Y_1^2)}$$

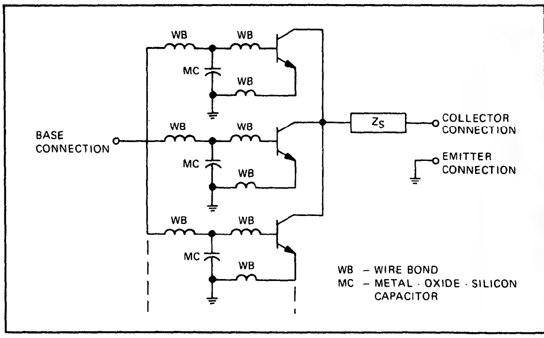



FIGURE 2 (a). Internal Matching, MRF646

FIGURE 2 (b)

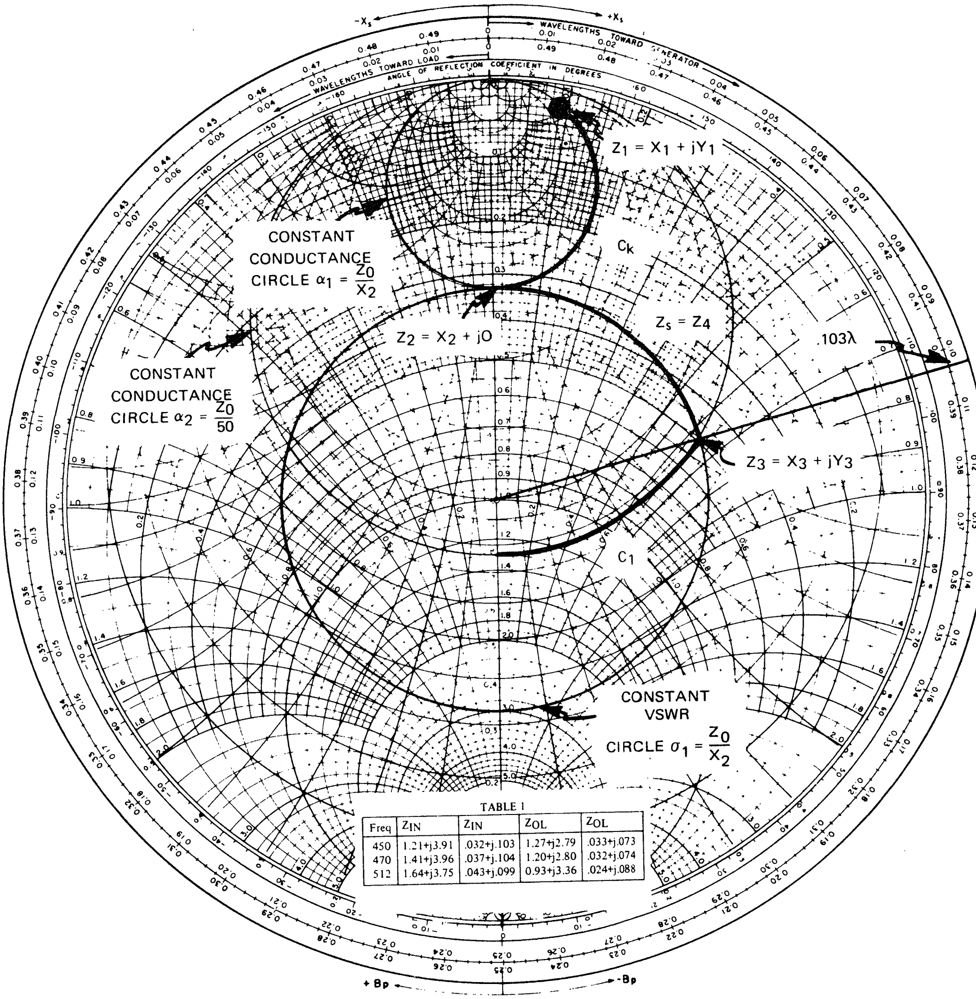



TABLE I

| Freq | $Z_{IN}$ | $Z_{IN}$ | $Z_{OL}$ | $Z_{OL}$ |
|---|---|---|---|---|
| 450 | 1.21+j3.91 | .032+j.103 | 1.27+j2.79 | .033+j.073 |
| 470 | 1.41+j3.96 | .037+j.104 | 1.20+j2.80 | .032+j.074 |
| 512 | 1.64+j3.75 | .043+j.099 | 0.93+j3.36 | .024+j.088 |

FIGURE 3. MRF646 Amplifier Input Network Design, 470MHz

The transmission line (characteristic impedance $Z_o$) will now transform the impedance ($Z_2 = X_2 + j0$) along the circle of constant VSWR ($\sigma_1 = Z_o/X_2$) toward the generator until it intersects the normalized constant conductance circle ($\bar{\alpha}_2 = \frac{Z_o}{50}$).

The characteristic impedance of the transmission line, $Z_o$, has to be greater than or equal to the geometric mean between $X_2$ and 50 ohms.

$$Z_o \geqslant \left[(X_2)(50)\right]^{1/2} \Omega = \left[\frac{(X_1{}^2 + Y_1{}^2)(50)}{X_1}\right]^{1/2} \Omega$$

Also, the characteristic impedance should be low enough to minimize $I^2R$ losses. In our design 38 ohms was chosen for the characteristic impedance.

The electrical length of the line may be obtained by drawing a line from the center of the chart through the point where $\sigma_1$ and $\bar{\alpha}_2$ intersected to the edge of the chart. The length in wavelengths is read from the scale marked "wavelengths toward generator." The length may also be obtained from the following expression:

$$\ell = \frac{\lambda g}{2\pi} \tan^{-1} \left[\frac{X_2 R_o - X_2{}^2}{Z_o{}^2 - R_o X_2}\right]^{1/2}$$

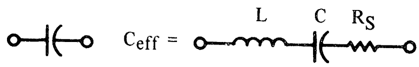
where $\lambda g$ is the guided wavelength
$R_o$ = source impedance (usually $50\Omega$)
valid for $Z_o^2 > R_oX_2$

One additional capacitor, $C_1$, will now finish the transform to $50 + j0\Omega$. The normalized capacitive reactance may be obtained by reading the susceptance where $\sigma_1 = \overline{\alpha}_2$ and taking its inverse or by using the relationship:

$$X_{c_1} = \frac{X_3^2 + Y_3^2}{Y_3}\ \Omega \text{ or } C_1 = \frac{Y_3}{(\omega)\,(X_3^2 + Y_3^2)}$$

The component values obtained by using these simple techniques will usually be good enough to get within a 2:1 VSWR across a moderate bandwidth. For more critical performance goals across wide bandwidths, computer aided designs or impedance matching tables may be used.

After a satisfactory theoretical design is completed, the components necessary to accomplish it must be chosen. Because of the parasitics associated with real components at this frequency and power level, this selection may be the major difficulty in realizing a design using idealized components. The parasitic elements associated with real capacitors are resistance and inductance which lower the Q and increase the effective capacitance. That is:




$$C_{eff} = \frac{C}{1 - \omega^2 LC} \qquad Q = \frac{X_{C_{eff}}}{R_s} = \frac{X_C - X_L}{R_S}$$

where C is the low frequency capacitance; L and $R_S$ are the associated high frequency parasitics.

This increase in the effective capacitance as frequency increases is an extremely undesirable effect and limits bandwidth as L increases. Table 2 gives values of parasitic L for different capacitors of use at UHF. As can be seen, the ceramic chip capacitor has the least parasitic inductance of those tested, and also has the highest Q.

Other parasitic elements of concern to the designer are those associated with transmission lines. This includes

TABLE 2

| Capacitor Type | Parasitic Inductance |
|---|---|
| ATC 50 mil chip capacitor | 0.3 nH |
| ATC 100 mil chip capacitor | 0.7 nH |
| ERIE 100 mil chip capacitor | 0.7 nH |
| UNELCO type capacitor | 2.5–10.0 nH* |

*Dependent On Mounting Configuration
Data taken at 50 and 100 MHz

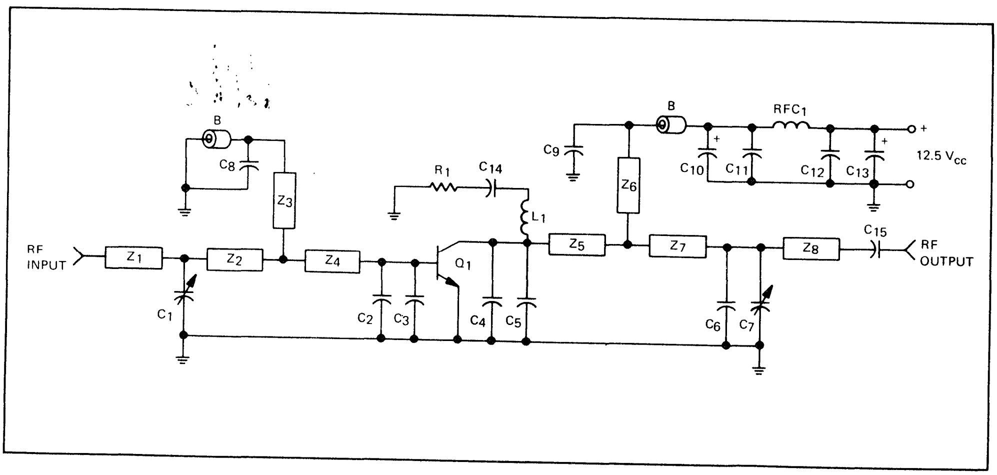



FIGURE 4. Schematic Diagram, 45W UHF Amplifier Using MRF646

resistance, dielectric losses and fringing capacitance. These parasitics, however, may be made negligible if proper layout techniques are used. These techniques include:

1. Keeping the ground plane greater than 3 dielectric thickness away from the line to prevent fringing capacitance.
2. Mitering any corners on the transmission line to eliminate discontinuities in $Z_O$ along the line in the form of small lumped capacitive mismatches.
3. Using as low a $Z_O$ line as possible to reduce the $I^2R$ losses.

Also important in the layout of the amplifier is the elimination of long ground returns. This is especially critical for components in the matching network that are at low impedance levels such as $C_2$ - $C_5$ (Figure 4). Here any additional inductance or resistance in the ground path will reduce the effective Q of the component. For this reason, two capacitors of equal value are used in parallel—one on each side of the transistor. This is not as critical for matching elements at higher impedance levels, but good grounds are still required. The backside of the circuit board should be a continuous ground plane and eyelets or plated through holes to the top side will reduce ground path lengths.

The prototype amplifiers were built on 3″ x 4″ printed circuit board with the series transmission lines and D.C. feeds printed on the board. The circuit board is 62 mil, 2-side, 2 oz. copper clad fiber glass reinforced teflon. The material was selected for dielectric consistency and low losses. ($\epsilon_R = 2.55, \delta = .0018$)

Printed collector and base D.C. feeds are high impedance $\lambda/4$ transmission lines and should be terminated with high Q chip capacitors. This combination provides very good isolation between device and supply line at the operating frequency. Further decoupling of the collector at frequencies where parasitic oscillations are likely to occur is provided by $C_{10}$, $C_{11}$, $C_{12}$, $C_{13}$, and $RFC_1$. (Figure 4.) A selective low frequency feedback network ($C_{14}$, $L_1$, $R_1$) from the collector to ground damps oscillations below 50 MHz during load mismatch.

Mounting the transistor should be given special consideration. The heatsink under the device should be flat (+.001″ - .000″) and a thin (≃ .001″) coat of thermal compound should be applied to the flange bottom before installation. To prevent stress to the transistor B.E.O., the leads should be level with the printed circuit board and the device should be secured to the heatsink before being soldered into the circuit.

| | UNELCO Capacitor Amplifier | Chip Capacitor Amplifier |
|---|---|---|
| $C_1$ | 5 pF UNELCO capacitor | 1-10 pF Johanson variable capacitor |
| $C_2$, $C_3$ | 30 pF UNELCO capacitor | 27 pF ATC 100 case B chip capacitor |
| $C_4$, $C_5$ | 30 pF UNELCO capacitor | 43 pF ATC 100 case B chip capacitor |
| $C_6$ | —— | 10 pF ATC 100 case B chip capacitor |
| $C_7$ | 1-10 pF Johanson variable capacitor | 1-10 pF Johanson variable capacitor |
| $C_8$, $C_9$ | 18,000 pF Vitromon chip capacitor | 18,000 pF Vitromon chip capacitor |
| $C_{10}$, $C_{13}$ | 1.0 μF 35v tantalum | 1.0 μF 35v tantalum |
| $C_{11}$, $C_{12}$ | 1000 pF UNELCO capacitor | 1000 pF UNELCO capacitor |
| $C_{14}$ | 0.1 μF ERIE ceramic capacitor | 0.1 μF ERIE ceramic capacitor |
| $C_{15}$ | 2-18,000 pF Vitromon chip capacitor | 150 pF ATC 100 case B chip capacitor |
| $Z_1$ | 0.350″ X 0.250″ microstrip | 0.90″ X 0.250″ microstrip |
| $Z_2$ | 1.55″ X 0.250″ microstrip | 1.01″ X 0.250″ microstrip |
| $Z_3$ | 4.2″ X 0.080″ microstrip ($\lambda/4$ @ 450 MHz) | 4.2″ X 0.080″ microstrip ($\lambda/4$ @ 450 MHz) |
| $Z_6$ | 4.2″ X 0.100″ microstrip ($\lambda/4$ @ 450 MHz) | 4.2″ X 0.100″ microstrip ($\lambda/4$ @ 450 MHz) |
| $Z_4$, $Z_5$ | 0.625″ X 0.250″ microstrip | 0.625″ X 0.250″ microstrip |
| $Z_7$ | 0.750″ X 0.250″ microstrip | 0.750″ X 0.250″ microstrip |
| $Z_8$ | 1.15″ X 0.250″ microstrip | 1.15″ X 0.250″ microstrip |
| $R_1$ | 10Ω 20% 1/4 W carbon resistor | 10Ω 20% 1/4 W carbon resistor |
| $L_1$ | 3T #22 AWG 0.095″ I.D. | 3T #22 AWG 0.095″ I.D. |
| $RFC_1$ | Ferroxcube VK200 - 20 - 4B | Ferroxcube VK200 - 20 - 4B |
| B | Ferroxcube bead 56 - 590 - 65 - 3B | Ferroxcube bead 56 - 590 - 65 - 3B |

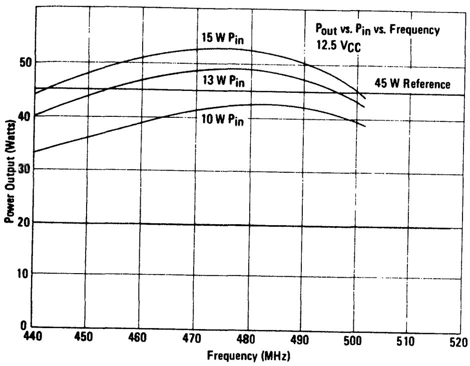
FIGURE 5. Parts List

# PERFORMANCE CURVES

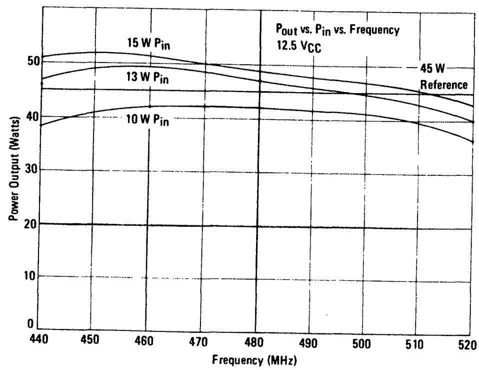
UNELCO Capacitor Amplifier

Chip Capacitor Amplifier

FIGURE 6

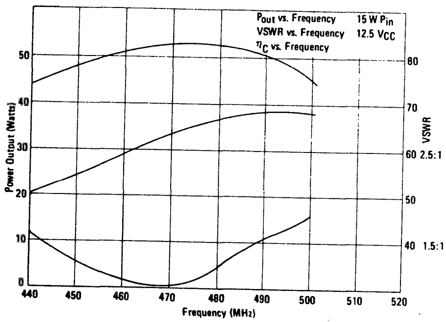



(a)

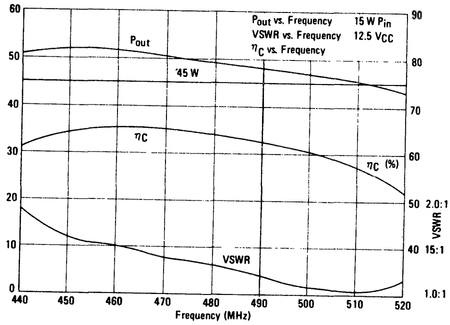



(b)

FIGURE 7

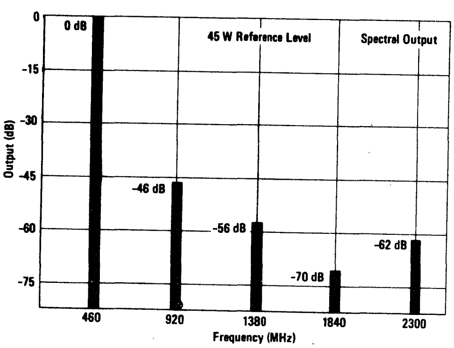



(a)




(b)

FIGURE 8

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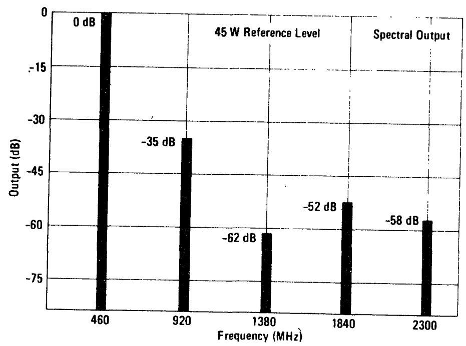


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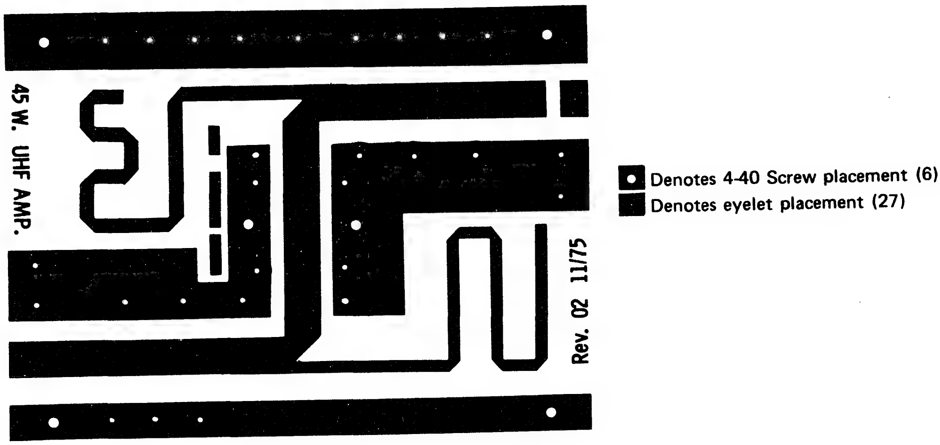



FIGURE 9. PC Board Layout

# MICROSTRIP DESIGN TECHNIQUES FOR UHF AMPLIFIERS

Prepared by:
**Glenn Young**

## INTRODUCTION

This note uses a 25 watt UHF amplifier design as a vehicle to discuss microstrip design techniques. The design concentrates on impedance matching and microstrip construction considerations. A basic knowledge of Smith chart techniques is helpful in understanding this note. [1]

The amplifier itself, as shown in Figure 1, provides 25 watts of output power in the 450 - 512 MHz UHF band. It is designed for 12.5 volt operation which makes it useful for mobile transmitting equipment. A variety of police, taxi, trucking and utility maintenance communication systems operate in this band.

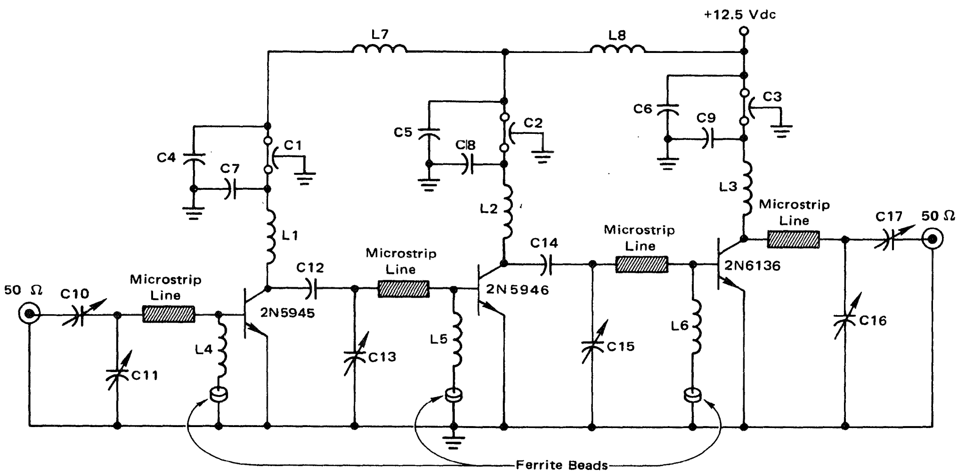
A summary of the performance of the completed amplifier operating with a 12.5 volt supply at 512 MHz indicates a power gain of 16 dB and a bandwidth (-1 dB) of 8 MHz. Overall efficiency is 48.5% and all harmonics are a minimum of 20 dB below the fundamental output.

Sections on construction and device handling considerations are also presented.

### MICROSTRIP DESIGN CONSIDERATIONS

Microstrip design was used for this amplifier due to its inherent superiority over other methods at this frequency. These techniques not only offer good compatibility with the Motorola "stripline" package but they also offer very good reproducibility. Microstrip construction is more efficient than lumped constant equivalents since microstrip lines are less lossy than lumped constant components.

Microstrip board with Teflon bonded fiberglass dielectric rather than the higher dielectric constant ceramics was chosen due to the ease of working with that type of material. A substrate thickness of 1/16-inch is convenient since a line of the same width as the transistor leads (0.225 inch) produces a reasonable characteristic impedance ($Z_O$) of 40.65 ohms. The value of the characteristic impedance is




All Microstrip lines 5.72 mm wide 2.5 cm long
C1,2,3, 470 pf feedthru
C4,5,6 1.0 μf Tantalum
C7,8,9 0.1 μf Ceramic
C10,11,13,15,16,17 1.5-20 pf Compression Trimmer ARCO 420
C12,14 10 pf Microwave capacitor ATC type 100-B-10-M-MS or equiv.
L1, L2, L3 – 5 turns #20 Closewound 3/16" I.D.
L4, L5, L6 – 0.15 μh molded choke
L7, L8 – Ferroxcube VK 200 20/4B or equiv.
Ferrite beads are Ferroxcube 56 590 65/3B or equiv.

**FIGURE 1 – Schematic Diagram of 25 W UHF Amplifier**

calculated from:[4]

$$Z_o = \frac{377h}{\sqrt{\epsilon_r} \times W \left[1 + 1.735\, \epsilon_r^{-.0724} \left(\frac{W}{h}\right)^{-.836}\right]} \quad (1)$$

where $\epsilon_r$ = dielectric constant
W = width of microstrip line
h = thickness of the dielectric

The h term is equal to the total thickness of the microstrip board minus the thickness of the copper on both sides. In this design that term is equal to

$$h = 62 - (2 \times 1.4) = 59.2 \text{ mils} \quad (2)$$

1 oz. copper = 1.4 mils thick

The effective width should be used when the conductor is of finite thickness.

$$W_{eff} = W + \frac{t}{\pi} \left(\ln \frac{2h}{t} + 1\right) \quad (3)$$

where t = thickness of the conductor

$$W_{eff} = 225 + (1.4/\pi) \left(\ln \frac{2 \times 59.2}{1.4} + 1\right) = 227.4 \text{ mils} \quad (4)$$

therefore:

$$Z_o = \frac{377 \times .0592}{\sqrt{2.5} \times .2274 \left[1 + 1.735 \times 2.5^{-.0724} \times \left(\frac{227.4}{59.2}\right)^{-.836}\right]} = 40.65\ \Omega \quad (5)$$

## THE AMPLIFIER DESIGN

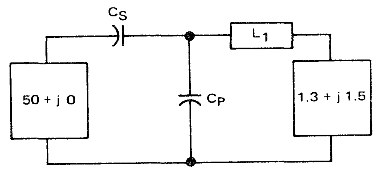
The first decision in the design was determining the type of matching networks to be used. The network shown in Figure 3 was chosen because of its ability to "map" a large area of complex impedances; this allows a good tuning margin to compensate for normal variations in transistor impedances and other peripheral effects. A side benefit of this network is that the series tuning element provides the dc blocking function, eliminating the need for coupling capacitors.

The synthesis of the matching networks utilizes the large signal impedances of the transistors as specified on the data sheets. These parameters should not be confused with small signal 2-port parameters. A complete discussion of large signal characterization is given in Motorola Application note AN-282A. The impedance parameters used in this note are taken from the respective data sheets and were obtained in the manner described in AN282A.

2N5945
$Z_{in}$ 1.3 + j1.5 ohms
$Z_{out}$ 4.6 - j5.4 ohms
2N5946
$Z_{in}$ 1.3 + j1.2 ohms
$Z_{out}$ 4.2 - j0.5 ohms
2N6136
$Z_{in}$ 1.3 + j 4.11 ohms
$Z_{out}$ 3.2 + j 1.96 ohms

**FIGURE 2 – Transistor Complex Input and Output Impedance at 470 MHz (Series Form)**

Smith chart techniques are used to synthesize the matching networks in the amplifier to be described. The complex series equivalent input and output impedances as taken from the data sheets are shown in Figure 2. There are an infinite number of solutions to the required matching networks, however, once an initial choice of one of the components is made, only one solution exists. It is obvious that all components need to be kept within reasonable limits, however it would seem that the most critical parameter is the length of the microstrip line. Using this assumption, the length of the line is chosen as a starting point. The input network, shown in Figure 3 will be solved to illustrate the technique.




$L_1$ = Microstrip Line 5.72 mm wide 2.5 cm long
$C_S$ = 4.08 pF
$C_p$ = 16.84 pf

**FIGURE 3 – Equivalent Circuit of Input Network**

Before proceeding to determine the component values, the effective wavelength of the desired frequency in the microstrip line must be known. This is accomplished by first finding $\lambda_o$, the wavelength in free space:

$$\lambda_o = \frac{c}{freq} = \frac{3 \times 10^8}{4.7 \times 10^8} = 0.638 \text{ meters} \quad (6)$$

where c = propagation constant, free space

The TEM mode wavelength is determined:

$$\lambda_{TEM} = \lambda_o / (\epsilon_r)^{1/2} = 63.8\text{cm} / (2.5)^{1/2} = 40.37\text{cm} \quad (7)$$

Now as the propagation in microstrip line is not pure TEM mode, a correction factor must be applied to the last calculation.[4]

$$K = \left[\frac{\epsilon_r}{1 + 0.63\,(\epsilon_r - 1)\left(\frac{W}{h}\right)^{.1225}}\right]^{1/2} = \left[\frac{2.5}{1 + 0.63\,(2.5-1)\,(227.4/59.2)^{.1225}}\right]^{1/2} = 1.086 \quad (8)$$

Then:

$$\lambda' = (\lambda tem)\,(K) = (40.37)\,(1.086) = 43.85 \text{ cm} \quad (9)$$

This is the effective wavelength and will be used in all further calculations. Equation 8 is valid for width to height ratios of 0.6:1 or greater. For ratios less than 0.6:1 alter the (w/h) factor in the denominator to $(w/h)^{.0297}$

The source and load impedances must now be normalized to the 40.65Ω characteristic impedance of the line and

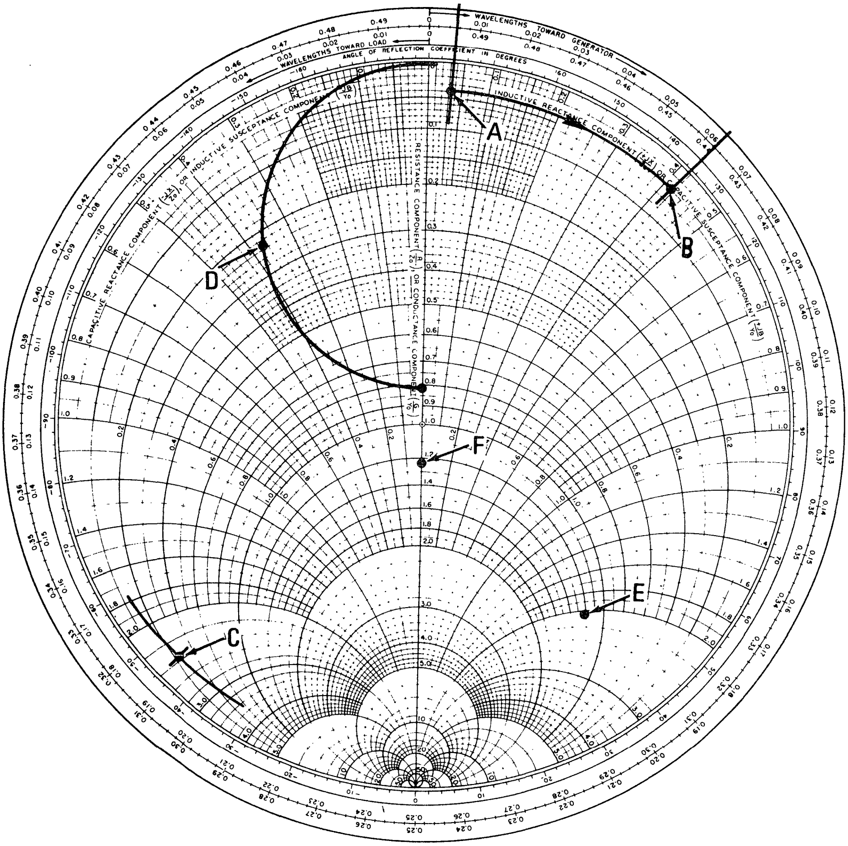



**FIGURE 4 – Smith Chart Solution**

plotted on the Smith chart. It should be noted that the terms "source" and "load" are used here only in reference to the Smith chart solution.

A source impedance of 50 + j0 is normalized to 1.23 + j0 and a load impedance of 1.3 + j1.5 is normalized to 0.032 + j0.0369. The load impedance is plotted at point A in Figure 4 and the source impedance at point F. An arbitrary choice of 2.5 cm for the line length was made. This is an electrical length of:

$$\text{electrical length} = \text{line length}/\lambda'$$
$$= 2.5\text{ cm}/43.85\text{ cm} = 0.057\,\lambda \quad (10)$$

Point A is rotated on a constant VSWR circle 0.057 λ toward the generator to point B. Reactance must now be added in parallel with the impedance presented at the end of the line just plotted. As parallel additions are more easily handled in admittance form, point B is converted to an admittance by rotating it one-quarter wavelength on the same constant VSWR circle. This results in point C in Figure 4. The constant conductance circle that point C lies on is noted to be 0.23. The problem now is to move along this circle towards the generator until the reciprocal of the constant resistance circle of the source impedance is intercepted. This circle does not exist on a standard Smith chart and must be constructed.

This is done by determining the radius of the constant resistance circle representing the real part of the source impedance and then constructing a circle of equal radius with its center on the real axis and its circumference tangent to the outer radius of the chart at zero resistance. When this is done the intercept with the 0.23 constant real circle is seen to lie at point D. The amount of parallel susceptance needed to move from point C to point D is:

$$B_{CP} = (B_C - B_D)(Y_o) =$$
$$(2.4 - 0.38)(24.6) = 49.72\text{ mmhos} \quad (11)$$

This is a parallel capacitance of:

$$C_P = B_{CP}/2\pi f = 49.72/(2\pi)(470 \times 10^6) = 16.84\text{ pF} \quad (12)$$

All that remains to finish the solution is to determine the amount of reactance necessary to reach the source at point F. To do this, it is first necessary to transpose point D, which is an admittance, to an impedance. This is accomplished by rotating point D one-quarter wavelength on a constant VSWR circle. This moves point D to point E which is on the 2.04 reactance line thus representing a series reactance of:

$$X_{CS} = (X_E) \bullet (Z_o) = (2.04) \bullet (40.65) = 82.9 \text{ ohms} \qquad (13)$$

A series capacitance with this reactance is:

$$C_S = \frac{1}{(2\pi)(f)(X_{CS})} = \frac{1}{(2\pi)(470 \times 10^6)(82.9)} = 4.08 \text{ pF} \qquad (14)$$

This completes the solution for the input network.

The interstage networks as well as the output network are solved in similar fashion with the following differences. In the case of the interstage networks when the imaginary term of the source impedance is other than zero, point F would be plotted at the complex conjugate of the source impedance. In the output network solution the "source" is the output load of the amplifier (50 + j0) and the "load" is the collector impedance of the output device.

| | 450 MHz | 480 MHz | 512 MHz |
|---|---|---|---|
| Power Gain | 18 db | 17.2 db | 16 db |
| Bandwidth (-1 db) | 5 MHz | 6 MHz | 8 MHz |
| Overall Efficiency | 44.5% | 46.5% | 48.5% |
| Harmonics | All Harmonics Better Than -20 db | | |
| Stability | Amplifier Stable under all Conditions of Drive down to $V_{CC}$ = 5.0 volts | | |
| Power Output | 25 w | 25 w | 25 w |
| Burnout | No Damage to any Transistor with Load Open & Shorted with 0 to ±180° Phase Angle | | |

**FIGURE 5 – Typical Performance Specifications**

Figure 5 gives details on the performance of the completed amplifier. The use of the porcelain dielectric chip capacitors for the series elements in the interstage networks was found to provide an additional 2.5 to 3.0 dB of gain over that obtained with compression trimmers as well as reducing the number of tuning adjustments necessary.

## CONSTRUCTION CONSIDERATIONS

As in all RF power applications, solid emitter grounds are imperative. In microstrip amplifiers gain can be increased more than 1 dB by grounding both of the emitter leads to the bottom foil of the microstrip board by wrapping strips of copper foil thru the transistor mounting hole as shown in Figure 6.

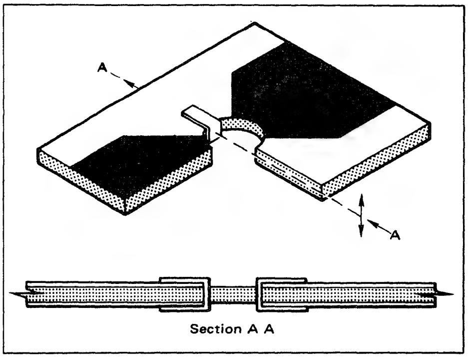



**FIGURE 6 – Proper Emitter Grounding Method**

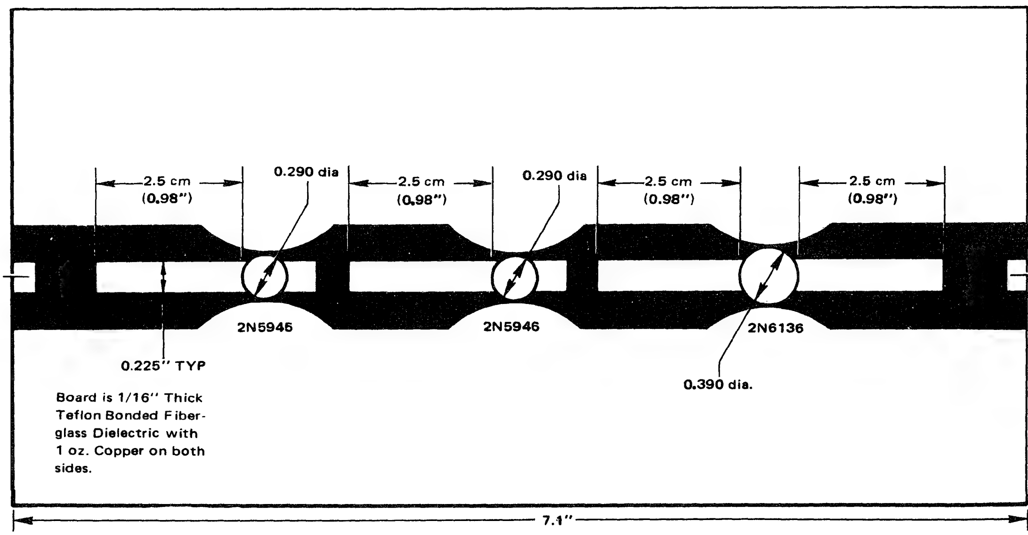



**FIGURE 7a – Microstrip Board Layout**

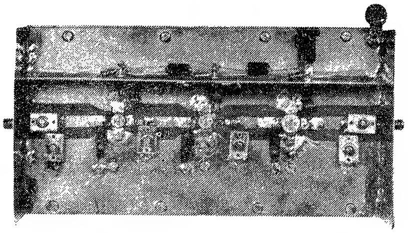


FIGURE 7b — Photograph of Amplifier

Stability under normal operating conditions is essential, however, stability should be maintained over as wide a range of supply voltage and drive levels as possible. If amplifier stability is maintained at all RF drive levels with the supply voltage reduced to between three and five volts, the designer can be practically certain that the amplifier will remain stable under all conditions of load. Maintaining stability is a key factor in protecting these transistors from damage. In a stable amplifier that has adequate heat sinking, these transistors will withstand high VSWR loads including open and shorted loads without damage. The major controlling factors in obtaining wide range stability are:

1) Mechanical layout: Good mechanical layout includes good emitter grounds (as previously described), compact layout and short ground paths.

2) Biasing: The devices are all zero biased for Class "C" operation. The use of relatively low Q base chokes with ferrite beads on the ground side will maintain good base circuit stability. In some applications, the use of a resistor in series with the ground side of the base chokes on the output and driver stages may enhance the stability. Approximate values of these resistors should be 10 ohms, 1/2 watt for the driver and 1.0 ohms, 1/2 watt for the output device. The addition of these series resistors will cause a slight loss in gain; (about 0.1 to 0.2 dB overall).

3) Collector supply feed method: The collector supply feed system is designed to provide decoupling at or near the operating frequency and a low collector load impedance at frequencies much lower than the operating frequency.

4) Heat sinking: In order to protect against burnout under all conditions of load, adequate heat-sinking must be provided. In heat sinking the device it is imperative to use a good grade of thermal compound, such as Dow-Corning 340, on the interface between the device and its heat sink.

Figure 7a shows the microstrip board layout while Figure 7b is a photo of the completed amplifier.

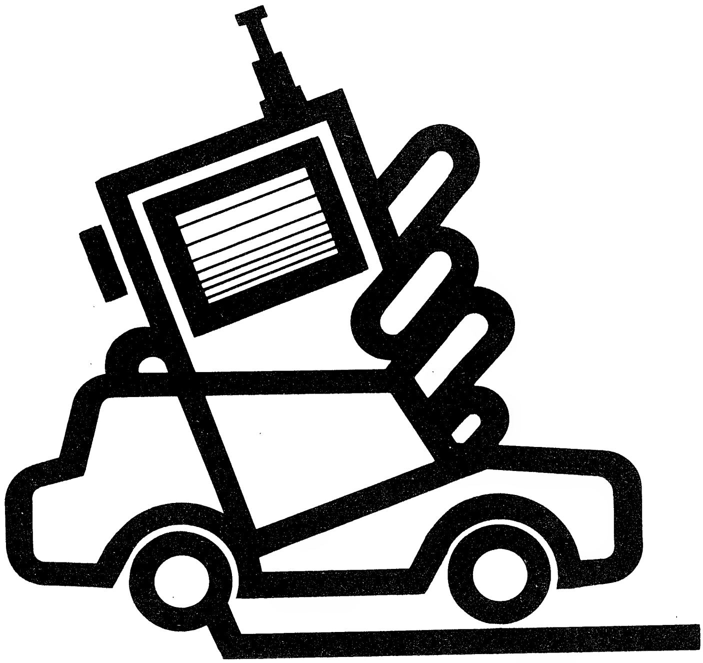
## DEVICE HANDLING CONSIDERATIONS

Although the Motorola stripline package is a rugged assembly, some care in its handling should be observed. The most important mechanical parameter is stud-torque, specified on the data sheet at 6.5 inch-pounds maximum. This data sheet specification is an absolute maximum and should not be exceeded under any circumstances. A good limit to use in production assembly is 6 inch-pounds and if for any reason repeated assembly/dissassembly is required torque should be limited to 5 inch-pounds.

Another major precaution to observe is to avoid upward pressure on the leads near the case body. Stresses of this type can crack or dislodge the cap. This type stress sometimes occurs due to adverse tolerance build-up in dimensions when the device is mounted thru a microstrip board onto a heat sink. Many times this type of stress is applied even in the most carefully thought out designs due to solder build-up on the copper foil when a device is replaced. In device replacement care should be taken to flow all solder away from the mounting area before the stud nut is torqued. Finally, one must be sure to torque the stud nut before soldering the device leads. Refer to Motorola Application Note AN-555 for details on mounting Motorola "stripline packaged transistors.

## REFERENCES


1. P. H. Smith, "Electronic Applications of the Smith Chart", McGraw-Hill, 1969.
2. H. A. Wheeler, "Transmission-Line Properties of Parallel Wide Strips by a Conformal-Mapping Approximation" IEEE Trans. Microwave Theory and Techniques Vol. MTT-12, May 1964.
3. H. A. Wheeler, "Transmission-Line Properties of Parallel Strips Separated by a Dielectric Sheet" IEEE Trans. Microwave Theory and Techniques Vol. MTT-3, March 1965.
4. H. Sobol "Extending Microwave and Technology to Microwave Equipment" Electronics, March 20, 1967.
5. Microwave Engineers Technical and Buyers Guide, Edition of the Microwave Journal, 1969.



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# MRF816

## The RF Line

0.75 W – 900 MHz

RF POWER
TRANSISTOR

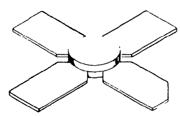
NPN SILICON

13

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 960 MHz.

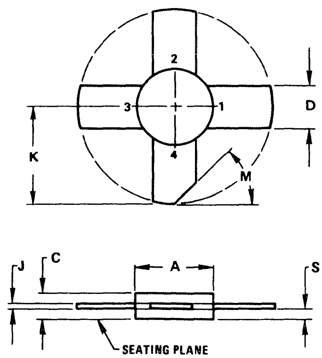
- Specified 12.5 Volt, 900 MHz Characteristics –
  Output Power = 0.75 Watts
  Minimum Gain = 10 dB
  Efficiency = 50%
- Characterized with Series Equivalent Large-Signal Impedance Parameters



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 175 | mAdc |
| Total Device Dissipation @ $T_C = 25^oC$ (1)<br>Derate above $25^oC$ | $P_D$ | 2.0<br>8.7 | Watts<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.




STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

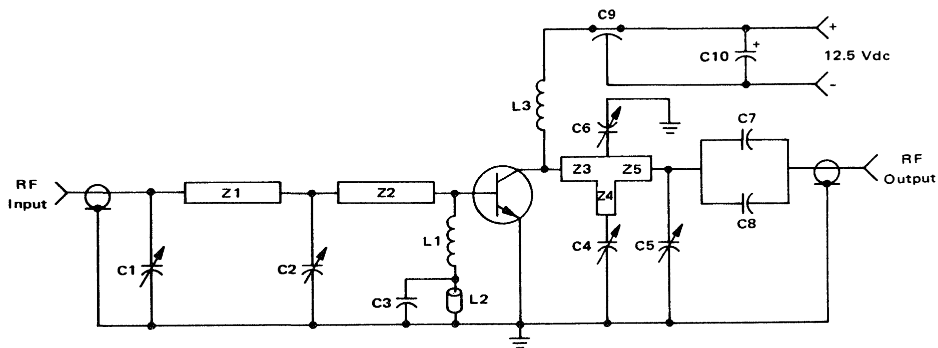
| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| C | 2.84 | 3.45 | 0.112 | 0.136 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| S | 1.40 | 1.65 | 0.055 | 0.065 |

CASE 249-05

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 5.0 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | 5.0 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 900 MHz) | $G_{PE}$ | 10 | 11 | – | dB |
| Collector Efficiency ($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 0.75 W, f = 900 MHz) | $\eta$ | 50 | – | – | % |

**FIGURE 1 – 900 MHz TEST CIRCUIT**




| | | | |
|---|---|---|---|
| C1,2,4,5,6 | 1.0-10 pF, JOHANSON 5201 | L3 | 5 Turns, #22 AWG, 0.1″ I.D., 0.35″ Long |
| C3 | 25 pF, UNELCO | Z1 | Microstripline, 0.3″ W x 2.0″L |
| C7,C8 | 15 pF, ATC, 50 x 50 Mils | Z2 | Microstripline, 0.3″ W x 0.5″ L |
| C9 | 680 pF, ALLEN BRADLEY Feedthru | Z3,Z4 | Microstripline, 0.3″ W x 0.6″ L |
| C10 | 1.0 µF, 35 V, TANTALUM | Z5 | Microstripline, 0.3″ W x 0.4″ L |
| L1 | 6 Turns, #26 AWG, 0.1″ I.D., 0.25″ Long, Bead on ground lead | | |
| L2 | Ferrite Bead, FERROXCUBE, 56-590-65-3B on Lead of L1 | | |

Board – Glass Teflon, $\epsilon_R$ = 2.56, t = 0.062″
Input/Output Connectors – Type N

13

FIGURE 2 – OUTPUT POWER versus INPUT POWER

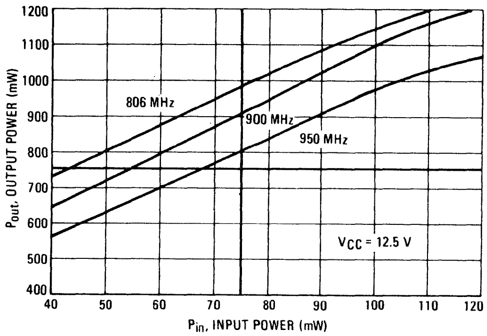



FIGURE 3 – OUTPUT POWER versus FREQUENCY

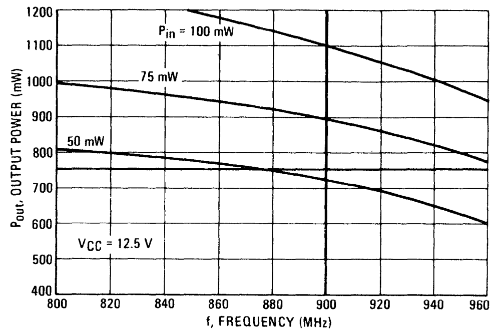



FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE

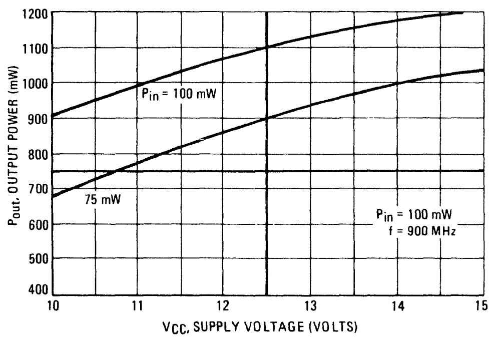
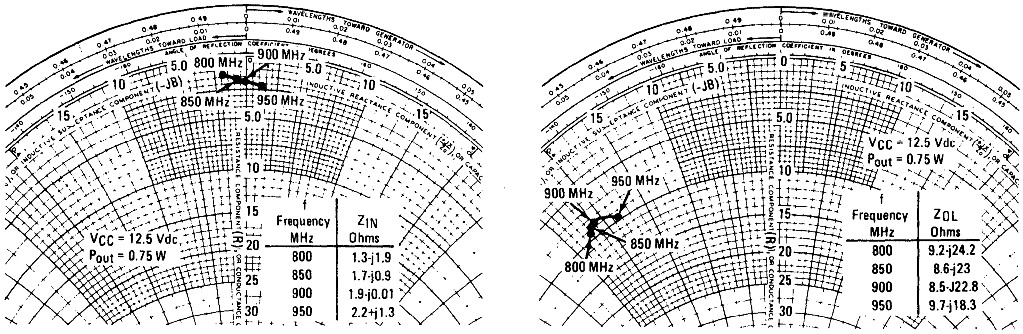



FIGURE 5 – SERIES EQUIVALENT IMPEDANCE




| f Frequency MHz | $Z_{IN}$ Ohms |
|---|---|
| 800 | 1.3-j1.9 |
| 850 | 1.7-j0.9 |
| 900 | 1.9-j0.01 |
| 950 | 2.2+j1.3 |

| f Frequency MHz | $Z_{OL}$ Ohms |
|---|---|
| 800 | 9.2-j24.2 |
| 850 | 8.6-j23 |
| 900 | 8.5-J22.8 |
| 950 | 9.7-j18.3 |

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# MRF817

## The RF Line

**2.5 W – 900 MHz**

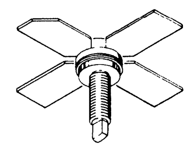
**RF POWER TRANSISTOR**

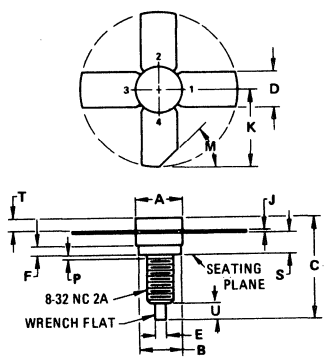
**NPN SILICON**

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 13.6 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 960 MHz.

- Specified 13.6 Volt, 900 MHz Characteristics –
  Output Power = 2.5 Watts
  Minimum Gain = 6.2 dB
  Efficiency = 50%
- Characterized with Series Equivalent Large-Signal Impedance Parameters






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.51 | 0.590 | 0.650 |
| D | 5.46 | 5.97 | 0.215 | 0.235 |
| E | 1.40 | 1.65 | 0.055 | 0.065 |
| F | 1.52 | – | 0.060 | – |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |

CASE 244-04

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque (2) | – | 6.5 | In. Lb. |

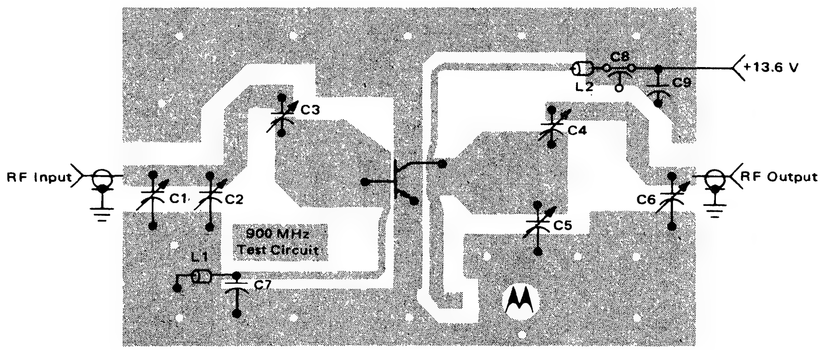
(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as Class C RF Amplifiers.

(2) For repeated assembly, use 5 In. Lb.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 1.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 40 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 15 | pF |
| **FUNCTIONAL TESTS** (Figure 1) | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 2.5 W, f = 900 MHz) | $G_{PE}$ | 6.2 | – | dB |
| Collector Efficiency ($V_{CC}$ = 13.6 Vdc, $P_{out}$ = 2.5 W, f = 900 MHz) | $\eta$ | 50 | – | % |

**FIGURE 1 – 900 MHz TEST CIRCUIT**




Microstrip Board

| | |
|---|---|
| C1,4 | 1.0-20 pF, JOHANSON S501 |
| C2,3,5,6 | 1.0-10 pF, JOHANSON S201 |
| C7 | 100 pF UNELCO |
| C8 | 680 pF, ALLEN BRADLEY Feedthru |
| C9 | 1.0 μF, 35 V TANTALUM |

L1,2 Ferrite Bead FERROXCUBE 56-590-65-4A on 1/2", #22 AWG

Board – Glass Teflon, $\epsilon_R$ = 2.56, t = 0.062"
Input/Output Connectors – Type N

**FIGURE 2 – OUTPUT POWER versus INPUT POWER**

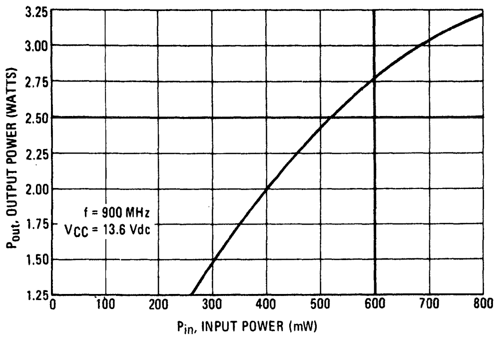



**FIGURE 3 – OUTPUT POWER versus FREQUENCY**

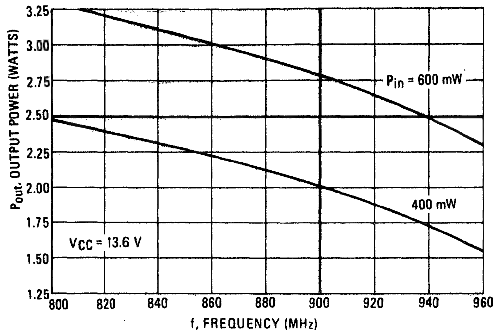



**FIGURE 4 – OUTPUT POWER versus SUPPLY VOLTAGE**

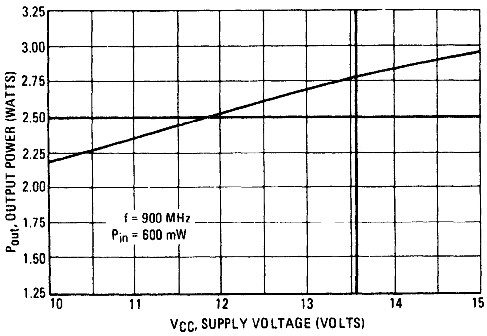
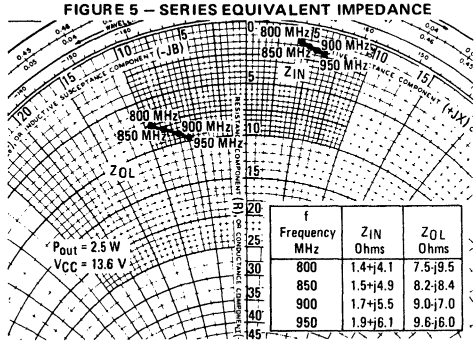


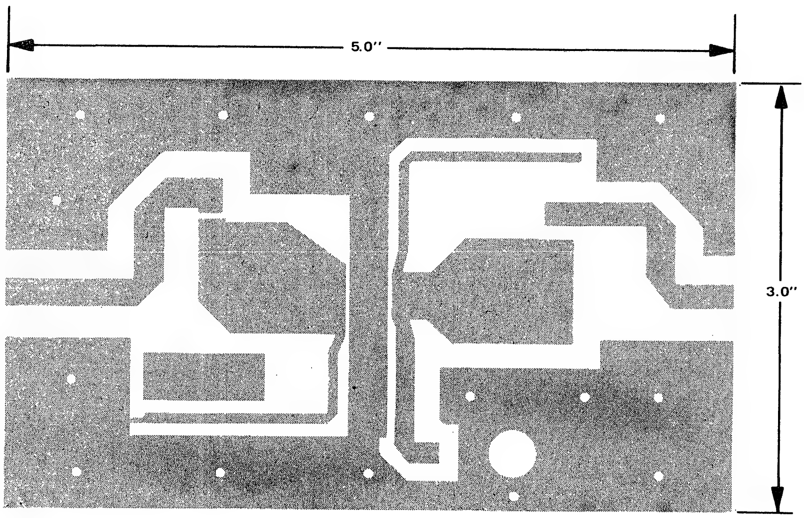

**FIGURE 5 – SERIES EQUIVALENT IMPEDANCE**




| f Frequency MHz | $Z_{IN}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 800 | 1.4+j4.1 | 7.5-j9.5 |
| 850 | 1.5+j4.9 | 8.2-j8.4 |
| 900 | 1.7+j5.5 | 9.0-j7.0 |
| 950 | 1.9+j6.1 | 9.6-j6.0 |

13

TEST CIRCUIT MASK DRAWING



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF838
# MRF838A

## Product Preview

## The RF Line

1 W–870 MHz

RF POWER
TRANSISTOR

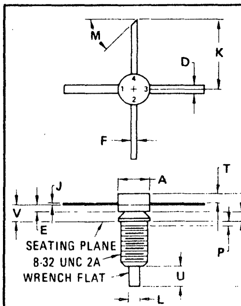
NPN SILICON

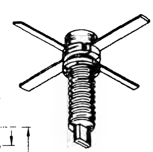
### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 volt UHF large-signal, common-emitter amplifier applications in industrial and commercial FM equipment operating in the range of 806-947 MHz.

- Specified 12.5 Volt, 870 MHz Characteristics:
  - Output Power = 1.0 Watt
  - Minimum Gain = 6.5 dB
  - Efficiency = 60% Typ
- Series Equivalent Large-Signal Characterization

MRF838A
CASE 305-01



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 13.97 | 16.26 | 0.550 | 0.640 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| L | 1.40 | 1.65 | 0.055 | 0.065 |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| S | 1.40 | 1.65 | 0.055 | 0.065 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.79 | 3.81 | 0.110 | 0.150 |
| V | 2.41 | 2.92 | 0.095 | 0.115 |

### MAXIMUM RATINGS

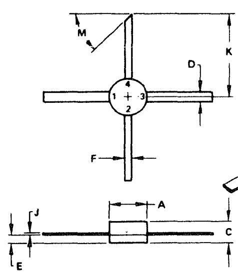
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 0.155 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C (1)<br>Derate Above 25°C | $P_D$ | 2.5<br>0.014 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

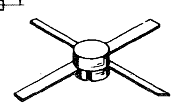
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 70 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

MRF838
CASE 305A-01



STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 5.08 | 5.59 | 0.200 | 0.220 |
| C | 2.41 | 3.30 | 0.095 | 0.130 |
| D | 1.40 | 1.65 | 0.055 | 0.065 |
| E | 1.02 | 1.27 | 0.040 | 0.050 |
| F | 0.64 | 0.89 | 0.025 | 0.035 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 11.05 | – | 0.435 | – |
| M | 45° NOM | | 45° NOM | |

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 5.0 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C = 25^oC$) | $I_{CES}$ | – | – | 1.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 5.0 | – | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($P_{out}$ = 1.0 W, $V_{CC}$ = 12.5 Vdc, f = 870 MHz) | $G_{PE}$ | 6.5 | 7.5 | – | dB |
| Collector Efficiency ($P_{out}$ = 1.0 W, $V_{CC}$ = 12.5 Vdc, f = 870 MHz) | $\eta$ | | 60 | – | % |

**SERIES EQUIVALENT INPUT/OUTPUT IMPEDANCE**
($V_{CC}$ = 12.5 Vdc, $P_{out}$ = 1.0 W)

| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 800 | 2.8 + j4.6 | 17.1 – j22.2 |
| 836 | 2.6 + j5.0 | 16.6 – j20.0 |
| 870 | 2.4 + j5.6 | 16.3 – j17.4 |
| 900 | 2.3 + j6.2 | 15.3 – j15.0 |

MOTOROLA
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# MRF840

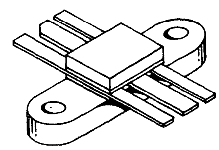
## Product Preview

## The RF Line

7 W–870 MHz

RF POWER
TRANSISTOR

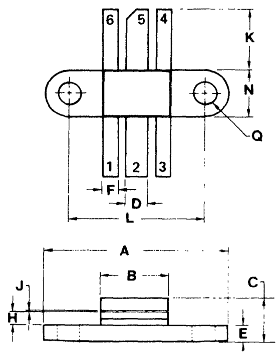
NPN SILICON



### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 volt UHF large-signal, common-base amplifier applications in industrial and commercial FM equipment operating in the range of 806–947 MHz.

- Specified 12.5 Volt, 870 MHz Characteristics:
  Output Power = 7.0 Watts
  Minimum Gain = 8.0 dB
  Efficiency = 50%
- Series Equivalent Large-Signal Characterization
- Internally Matched Input for Broadband Operation
- 100% Tested for Load Mismatch Stress at All Phase Angles with 20:1 VSWR @ 16 Volt Supply and 50% RF Overdrive




STYLE 1:
PIN 1. BASE
2. EMITTER
3. BASE
4. BASE
5. COLLECTOR
6. BASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 25.15 | 25.65 | 0.990 | 1.010 |
| B | 8.76 | 9.02 | 0.345 | 0.355 |
| C | 5.72 | 6.48 | 0.225 | 0.255 |
| D | 2.92 | 3.18 | 0.115 | 0.125 |
| E | 2.29 | 2.54 | 0.090 | 0.100 |
| F | 1.78 | 2.03 | 0.070 | 0.080 |
| H | 1.65 | 1.90 | 0.065 | 0.075 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 7.87 | 8.64 | 0.310 | 0.340 |
| L | 18.42 | BSC | 0.725 | BSC |
| N | 6.22 | 6.48 | 0.245 | 0.255 |
| Q | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 319-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 1.75 | Adc |
| Total Device Dissipation @ $T_C = 25^\circ C$ (1)<br>Derate Above $25^\circ C$ | $P_D$ | 30<br>0.23 | Watts<br>$W/^\circ C$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^\circ C$ |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 4.4 | $^\circ C/W$ |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25°C$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C = 50$ mAdc, $I_B = 0$) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C = 50$ mAdc, $V_{BE} = 0$) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E = 5.0$ mAdc, $I_C = 0$) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB} = 15$ Vdc, $I_E = 0$) | $I_{CBO}$ | – | – | 2.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C = 1.0$ Adc, $V_{CE} = 5.0$ Vdc) | $h_{FE}$ | 10 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB} = 12.5$ Vdc, $I_E = 0$, f = 1.0 MHz) | $C_{ob}$ | – | 20 | – | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Base Amplifier Power Gain ($P_{out} = 7.0$ W, $V_{CC} = 12.5$ Vdc, f = 870 MHz) | $G_{PE}$ | 8.0 | 9.0 | – | dB |
| Collector Efficiency ($P_{out} = 7.0$ W, $V_{CC} = 12.5$ Vdc, f = 870 MHz) | $\eta$ | 50 | 55 | – | % |
| Load Mismatch Stress ($V_{CC} = 16$ Vdc, $P_{in} = 1.32$ W,* f = 870 MHz, VSWR = 20:1, all phase angles) | – | No Degradation in Output Power | | | |

*$P_{in}$ = 150% of the typical input power requirement for 7 W output power @ 12.5 Vdc.

**SERIES EQUIVALENT INPUT/OUTPUT IMPEDANCE**

($V_{CC} = 12.5$ Vdc, $P_{in} = 1.1$ W, $P_{out} = 7.0$ W)

| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 800 | 2.0 + j6.1 | 3.3 – j0.4 |
| 836 | 2.0 + j6.2 | 3.0 – j0.2 |
| 870 | 2.1 + j6.3 | 2.5 + j0.0 |
| 900 | 2.0 + j6.8 | 2.0 + j0.3 |

MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF842

## Product Preview

## The RF Line

20 W—870 MHz

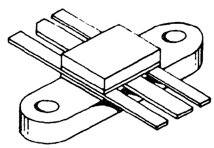
RF POWER TRANSISTOR

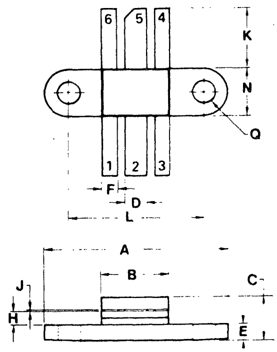
NPN SILICON

### NPN SILICON RF POWER TRANSISTOR

. . . designed for 12.5 volt UHF large-signal, common-base amplifier applications in industrial and commercial FM equipment operating in the range of 806-947 MHz.

- Specified 12.5 Volt, 870 MHz Characteristics:
  - Output Power = 20 Watts
  - Minimum Gain = 6.0 dB
  - Efficiency = 50%
- Series Equivalent Large-Signal Characterization
- Internally Matched Input for Broadband Operation
- 100% Tested for Load Mismatch Stress at All Phase Angles with 20:1 VSWR @ 16 Volt Supply and 50% RF Overdrive






STYLE 1:
PIN 1. BASE
2. EMITTER
3. BASE
4. BASE
5. COLLECTOR
6. BASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 25.15 | 25.65 | 0.990 | 1.010 |
| B | 8.76 | 9.02 | 0.345 | 0.355 |
| C | 5.72 | 6.48 | 0.225 | 0.255 |
| D | 2.92 | 3.18 | 0.115 | 0.125 |
| E | 2.29 | 2.54 | 0.090 | 0.100 |
| F | 1.78 | 2.03 | 0.070 | 0.080 |
| H | 1.65 | 1.90 | 0.065 | 0.075 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 7.87 | 8.64 | 0.310 | 0.340 |
| L | 18.42 | BSC | 0.725 | BSC |
| N | 6.22 | 6.48 | 0.245 | 0.255 |
| Q | 3.05 | 3.30 | 0.120 | 0.130 |

CASE 319-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 16 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 36 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 4.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 3.5 | Adc |
| Total Device Dissipation @ $T_C = 25°C$ (1)<br>Derate Above 25°C | $P_D$ | 60<br>0.46 | Watts<br>W/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 2.2 | °C/W |

(1) These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 16 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 50 mAdc, $V_{BE}$ = 0) | $BV_{CES}$ | 36 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 5.0 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.0 Adc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 10 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Output Capacitance ($V_{CB}$ = 12.5 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 40 | – | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Base Amplifier Power Gain ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, f = 870 MHz) | $G_{PE}$ | 6.0 | 7.5 | – | dB |
| Collector Efficiency ($P_{out}$ = 20 W, $V_{CC}$ = 12.5 Vdc, f = 870 MHz) | $\eta$ | 50 | 55 | – | % |
| Load Mismatch Stress ($V_{CC}$ = 16 Vdc, $P_{in}$* = 5.33 W, f = 870 MHz, VSWR = 20:1, all phase angles) | – | No Degradation in Output Power | | | |

*$P_{in}$ = 150% of the typical input power requirement for 20 W output power @ 12.5 Vdc.

**SERIES EQUIVALENT INPUT/OUTPUT IMPEDANCE**
($V_{CC}$ = 12.5 Vdc, $P_{in}$ = 5.0 W, $P_{out}$ = 20 W)

| f MHz | $Z_{in}$ Ohms | $Z_{OL}$ Ohms |
|---|---|---|
| 800 | 1.07 + j4.1 | 1.9 + j1.5 |
| 836 | 1.2 + j4.3 | 1.9 + j1.6 |
| 870 | 1.4 + j4.4 | 1.8 + j1.7 |
| 900 | 1.6 + j4.5 | 1.8 + j1.8 |

# POWER AMPLIFIER MODULES CHAPTER 14

# POWER AMPLIFIER MODULES

Since their introduction five years ago, Motorola RF Power Modules have enjoyed worldwide acceptance in VHF/UHF communications applications. Keys to this acceptance have been three major factors: cost-effectiveness, reliability, and size. Modules are produced in sizes, voltages, and power levels suitable for portable and mobile radio applications, either as output stages or drivers for higher power stages.

When considering the use of a module to provide a function, as opposed to a discrete design, one should consider at least the following factors: first, a reduction in engineering time for the power amplifier design; second, the reduction in inventory, purchasing, specification, and assembly costs associated with the many components needed for a discrete design.

The power modules are designed to be stable with load VSWR up to 6:1, at any phase angle. Also, they are designed to be stable with combinations of reduced drive, reduced voltage, and overdrive with increased voltage. The dc decoupling network is also a major factor in the stable operation of a module. The recommended decoupling network shown on the data sheet should be followed as closely as possible.

The active devices used in the modules are similar to standard Motorola devices, but are usually processed with somewhat different starting materials and diffusions in order to optimize their performance for specific module applications.

Also, this means the devices are from a dedicated line, run only for module applications, and can be held to close tolerances for good module repeatability. All devices used in the modules are glass-passivated. The transistors are selected to run at a current density less than $1.5 \times 10^5$ A/cm$^2$ and thermal design is such that a worst-case device should run at less than 165°C junction temperature with a 100°C heat-sink temperature.

The capacitors used in the networks are either NPO or MOS for values under about 1000 pF and GP dielectric for capacitors above 1000 pF. MOS capacitors are produced in-house on a dedicated line and are used in locations where higher Q is necessary than is available with NPO capacitors.

Nichrome is used as the adhesion layer to the ceramic and, through photolithographic process, also serves as the resistors in the circuit. The resistors are laser-trimmed to the desired value for the circuit. The transmission lines on the board are built up to proper thickness for the frequencies involved by plating up copper. Next, gold is plated for die and wirebonding purposes.

The majority of the input, output, and interstage impedance matching networks are of low-pass Chebyshev design. Most of the earlier designs used 50-ohm interface levels between stages; however, more recent designs use direct interstage matching between the stages where applicable.

The design philosophy for newer designs is based on wider use of MOS capacitors, use of BeO tape-process substrates where applicable, and considerable effort is spent in the design process to reduce the size of the final circuit as much as possible. This reduction in size is a major factor in holding or reducing the cost of producing given module functions.

The applications information supplied covers most of the usual circuit configurations. It is not possible, however, to anticipate all applications and should any difficulties be encountered, please contact the factory via your local Motorola Sales Office or distributor for assistance with your particular problem.

# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MHW401

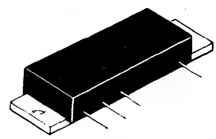
## The RF Line

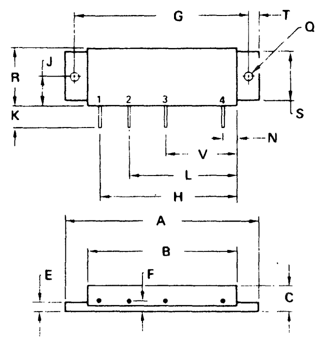
1.5 W – 512 MHz
**RF POWER AMPLIFIER MODULE**

### UHF POWER AMPLIFIER MODULE

. . . designed for 7.5 volt UHF power amplifier applications in portable FM equipment operating to 512 MHz.

- Specified 7.5 Volt, UHF Characteristics –
  Output Power = 1.5 Watts
  Minimum Gain = 15 dB
  Harmonics = -45 dB
- Frequency Range – 400 to 512 MHz
- Gain Control Pin for Constant Output Power Level






STYLE 1.
PIN 1. RF INPUT
2. DC GAIN
3. DC TERM.
4. RF OUTPUT
CASE. GROUND

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 48.13 | 48.39 | 1.895 | 1.905 |
| B | 33.15 | 33.40 | 1.305 | 1.315 |
| C | 5.84 | 6.86 | 0.230 | 0.270 |
| E | 1.32 | 1.83 | 0.052 | 0.072 |
| F | 2.21 | 2.84 | 0.087 | 0.112 |
| G | 41.15 | 41.40 | 1.620 | 1.630 |
| H | 30.35 | 30.61 | 1.195 | 1.205 |
| J | 7.49 | 7.75 | 0.295 | 0.305 |
| K | 6.73 | 8.51 | 0.265 | 0.335 |
| L | 22.73 | 22.98 | 0.895 | 0.905 |
| N | 2.41 | 2.67 | 0.095 | 0.105 |
| Q | 2.92 | 3.18 | 0.115 | 0.125 |
| R | 17.14 | 17.40 | 0.675 | 0.685 |
| S | 15.11 | 15.37 | 0.595 | 0.605 |
| T | 3.35 | 3.61 | 0.132 | 0.142 |
| V | 15.11 | 15.37 | 0.595 | 0.605 |

CASE 301-01

### ELECTRICAL CHARACTERISTICS

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Frequency Range (1) | – | 400 | 512 | MHz |
| Output Power (2) (50-Ohm Load)<br>($P_{in}$ = 50 mW, $V_s$ = 7.5 Vdc) | $P_{out}$ | 1.5 | 2.0 | Watts |
| Power Gain | $G_p$ | 15 | – | dB |
| Efficiency (2)<br>($P_{out}$ = 1.5 W, $V_s$ = 7.5 Vdc) | $\eta$ | 40 | – | % |
| Harmonics (2)<br>($P_{out}$ = 1.5 W, Reference) | – | – | -45 | dB |
| Input Impedance (2)<br>($P_{out}$ = 1.5 W, 50 Ohm Reference) | $Z_{in}$ | – | 2:1 | VSWR |
| Power Degradation (2)<br>($P_{out}$ = 1.5 W, $T_C$ = 25°C)<br>($T_C$ = 0°C to 60°C) | – | – | 0.3 | dB |
| Power Degradation (2)<br>($P_{out}$ = 1.5 W, $T_C$ = 25°C)<br>($T_C$ = 0°C to 80°C) | – | – | 0.7 | dB |
| Load Mismatch<br>(VSWR = ∞, $V_s$ = 11 Vdc, $V_{sc}$ set for $P_{out}$ = 2.0 W) | – | No degradation in $P_{out}$ | | |
| Stability<br>($P_{in}$ = 25 to 75 mW, Load Mismatch 10:1 50 ohm reference, $V_s$ = 4.0 to 11 Vdc, $V_{sc}$ adjusted for $P_{out}$ = 0.5 to 2.0 W) | – | All spurious outputs more than 60 dB below desired signal | | |

(1) Frequency Range is covered in three bands: MHW401-1 400-440 MHz
MHW401-2 440-470 MHz
MHW401-3 470-512 MHz

(2) $P_{in}$ = 50 mW, $V_{sc}$ Adjusted for 1.5 W Output

## APPLICATIONS INFORMATION

**Nominal Operation**

All electrical specifications are based on the nominal conditions: Pin 2 voltage (control pin – $V_{SC}$) and Pin 3 voltage (main supply or $V_S$) equal to 7.5 Vdc and with output power equaling to 1.5 watts. With these conditions, maximum current density on any device is $1.5 \times 10^5$ A/cm$^2$ and maximum die temperature with 100°C base plate temperature is 165°C. While the modules are designed to have excess gain margin with ruggedness, operation of these units outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

**Gain Control**

The input stage in this module is designed to have good input VSWR with varying drive and voltage conditions. This is accomplished by running the stage essentially Class A.

Maximum module DC to RF conversion efficiency is obtained by applying full input drive, output power set to 1.5 Watts by reducing the voltage on Pin 2 ($V_{SC}$). This can be done with a variable resistor or through a series pass transistor such as in an AGC loop. Input VSWR even under heavy AGC application or overdrive to 80 mW will generally remain under 2:1.

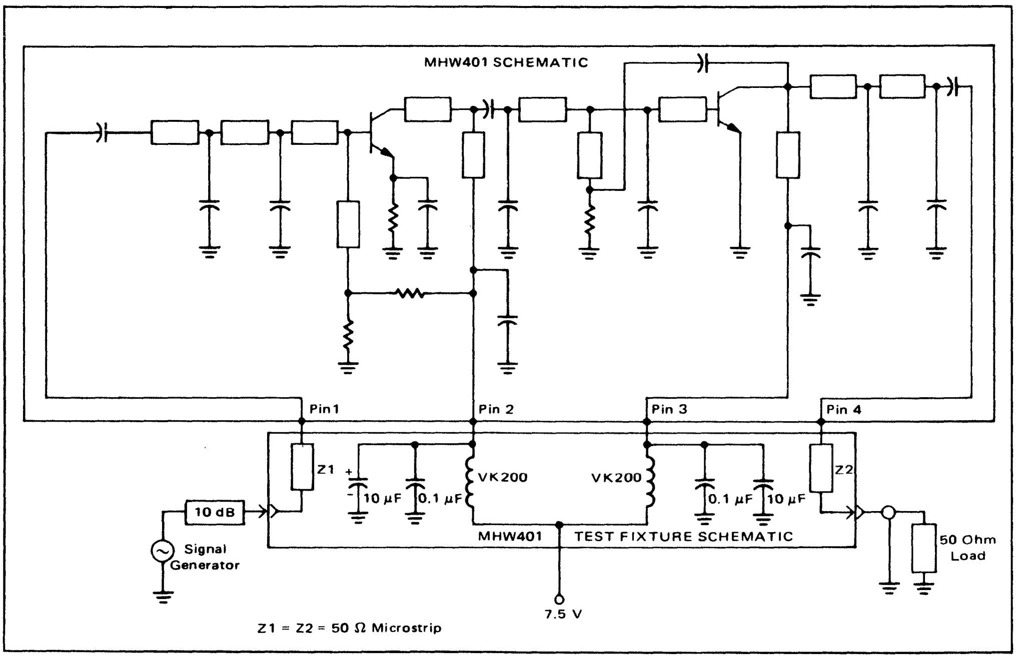
**Decoupling**

The high gain of the two stages and the module size limitations, external decoupling network requires careful consideration. Both Pins 2 and 3 are internally bypassed with a 0.018 µF chip capacitor effective for frequencies from 5 through 1000 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic are recommended. Inadequate decoupling will result in spurious outputs at certain operating frequencies and certain phase angles of input and output VSWR greater than 3:1.

**Load Pull**

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrical conditions are $V_S$ and $V_{SC}$ equal 11 V, output VSWR infinite, output power obtained with 80 mW drive – lowest frequency in the band.

FIGURE 1 – UHF POWER MODULE TEST SETUP



## TYPICAL PERFORMANCE CURVES

**FIGURE 2 — INPUT POWER, EFFICIENCY, AND VSWR versus FREQUENCY**

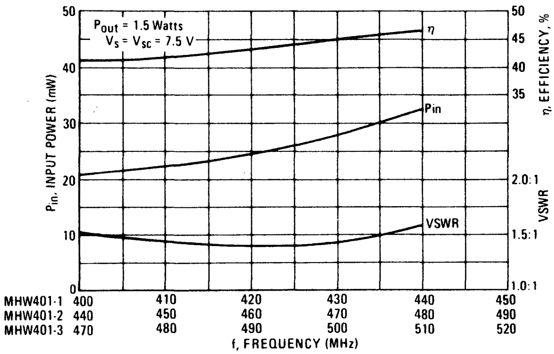



**FIGURE 3 — OUTPUT POWER versus INPUT POWER**

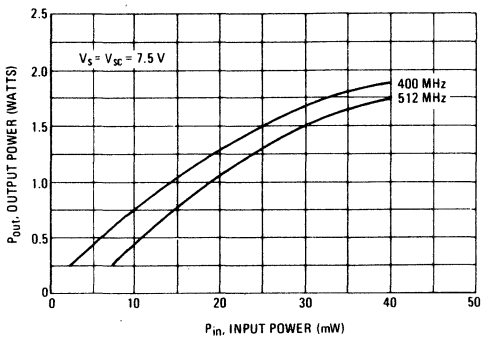



**FIGURE 4 — OUTPUT POWER versus VOLTAGE**

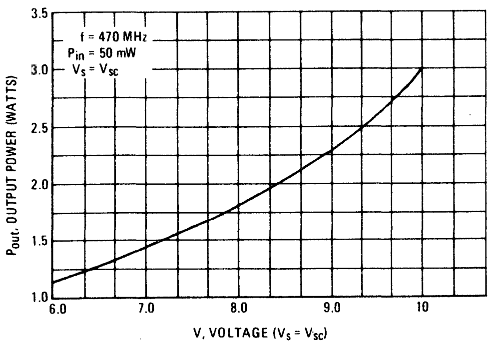


FIGURE 5 – TEST CIRCUIT

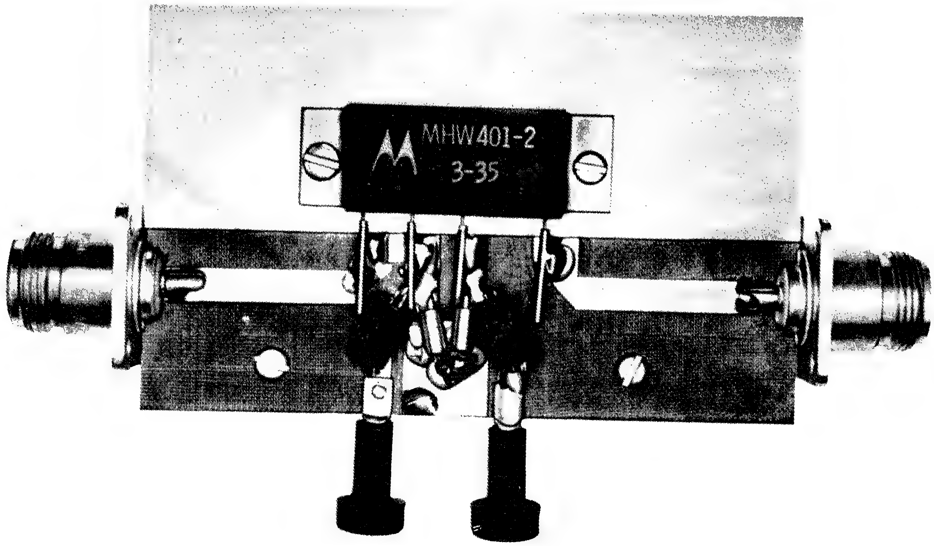
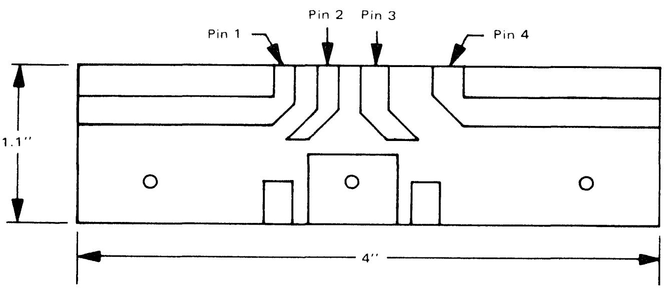



FIGURE 6 – UHF POWER MODULE TEXT FIXTURE
PRINTED CIRCUIT BOARD




Teflon Glass Board
t = 0.062"
$\epsilon_R$ = 2.56

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# MHW601

## The RF Line

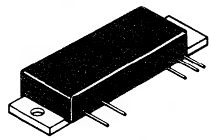
13 W — 174 MHz

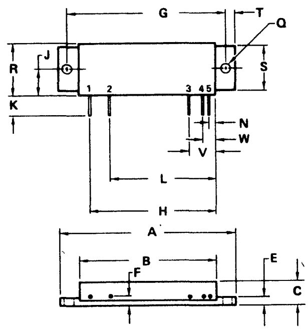
RF POWER
AMPLIFIER MODULE

## VHF POWER AMPLIFIER MODULE

. . . designed for 12.5 volt VHF power amplifier applications in industrial and commercial FM equipment operating to 174 MHz.

- Specified 12.5 Volt, 174 MHz Characteristics —
  Output Power = 13 Watts
  Minimum Gain = 21 dB
  Harmonic Content = -30 dB
- Frequency Range — 146 to 174 MHz
- Gain Control Pin for Constant Power Output Level






STYLE 1:
PIN 1. RF OUTPUT
2. D.C. TERM.
3. D.C. GAIN
4. GROUND
5. RF INPUT

NOTE:
1. MOUNTING HOLES WITHIN .13 (.005) DIA. OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 67.06 | 67.56 | 2.640 | 2.660 |
| B | 51.82 | 52.96 | 2.040 | 2.085 |
| C | 8.51 | 9.14 | 0.335 | 0.360 |
| E | 2.54 | 2.92 | 0.100 | 0.115 |
| F | 2.67 | 2.92 | 0.105 | 0.115 |
| G | 61.09 BSC | | 2.405 BSC | |
| H | 47.88 | 48.64 | 1.885 | 1.915 |
| J | 10.16 | 11.18 | 0.400 | 0.440 |
| K | 5.84 | 7.62 | 0.230 | 0.300 |
| L | 40.26 | 41.02 | 1.585 | 1.615 |
| N | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.45 | 3.71 | 0.136 | 0.146 |
| R | 20.32 | 20.83 | 0.800 | 0.820 |
| S | 17.02 | 17.53 | 0.670 | 0.690 |
| T | 2.98 | 3.24 | 0.1175 | 0.1275 |
| V | 9.78 | 10.54 | 0.385 | 0.415 |
| W | 4.70 | 5.46 | 0.185 | 0.215 |

CASE 297-02

**ELECTRICAL CHARACTERISTICS** ($V_S$ and $V_{SC}$ @ 125 Vdc unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Frequency Range | — | 146 | 174 | MHz |
| Input Power ($P_{out}$ = 13 W) | $P_{in}$ | — | 100 | mW |
| Power Gain | $G_p$ | 21 | — | dB |
| Efficiency ($P_{out}$ = 13 W) | $\eta$ | 40 | — | % |
| Operating Voltage | — | — | 12.5 | Vdc |
| Harmonic Content ($P_{out}$ = 13 W, Reference) | — | — | -30 | dB |
| Input Impedance ($P_{out}$ = 13 W, 50 Ohm Reference) | $Z_{in}$ | — | 2.0:1 | VSWR |
| Power Degradation ($P_{out}$ = 13 W, $T_C$ = 25°C) ($T_C$ = 0°C to 60°C) | — | — | 0.3 | dB |
| Power Degradation ($P_{out}$ = 13 W, $T_C$ = 25°C) ($T_C$ = 0°C to 80°C) | — | — | 0.7 | dB |
| Load Mismatch (VSWR = ∞, $V_s$ = 15.5 Vdc, $P_{out}$ = 19 W) | — | No degradation in $P_{out}$ | | |
| Stability ($P_{in}$ = 10 to 200 mW, $V_s$ = 4.0 to 15 V, Load and Source Mismatch 4:1, 50 Ohm Reference, $V_s$ = 4.0 to 16 Vdc, $V_{SC}$ adjusted for $P_{out}$ = 7.0 to 18 W) | — | All spurious outputs more than 70 dB below desired signal | | |

## APPLICATIONS INFORMATION

**Nominal Operation**

All electrical specifications are based on the nominal conditions of Pin 3 voltage (control pin – $V_{SC}$) and Pin 2 voltage (main supply – $V_S$) equal 12.5 volts with output power equaling 13 watts. With these conditions, maximum current density on any device is 1.5 x $10^5$ A/cm$^2$ and maximum die temperature with 100°C base plate temperature is 150°C. While the modules are designed to have excess gain margin with ruggedness, operation of these units outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

**Gain Control**

In general, the module output power should be limited to 16 watts. The preferred method of power output control is to fix both $V_{SC}$ and $V_S$ at 12.5 volts and to vary the input RF drive level at Pin 5. The next method is to control $V_{SC}$ through a stiff voltage source.

A third method of power output control is to control $V_{SC}$ through a current source or voltage source with series resistance. This mode of control creates a region of negative slope on the power gain profile curve and aggravates output power slump with temperature.

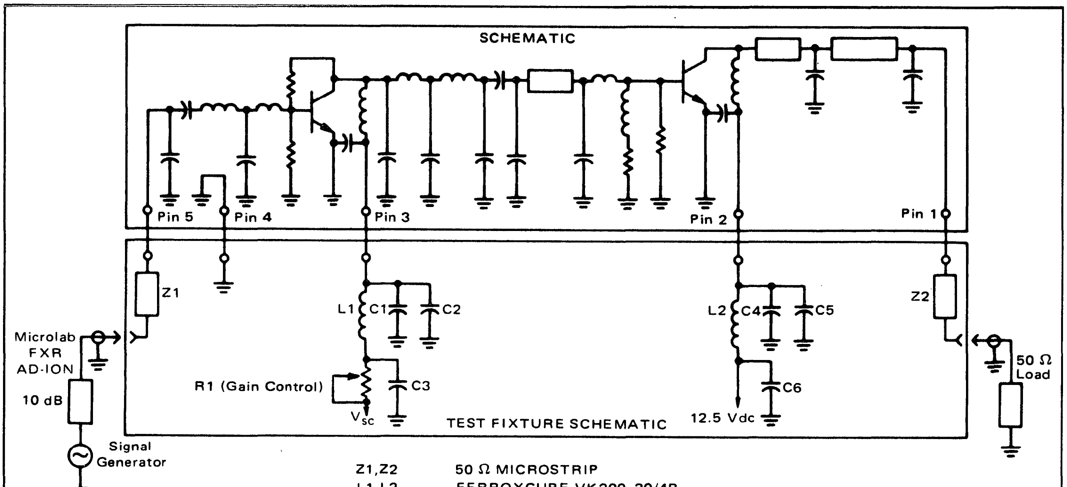
**Decoupling**

Due to the high gain of each of the two stages and the module size limitation, the external decoupling networks require careful consideration. Both Pins 2 and 3 are internally bypassed with an 0.018 mF chip capacitor effective for frequencies of 5 MHz through 174 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic are recommended. Inadequate decoupling will result in spurious outputs at specific operating frequencies and phase angles of input and output VSWR less than 4:1.

**Load Pull**

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrcial conditions are $V_S$ and $V_{SC}$ equal to 15.5 volts output, VSWR 20:1, and output power equal to 19 watts.

FIGURE 1 – VHF MODULE TEST SET UP




| | |
|---|---|
| Z1,Z2 | 50 Ω MICROSTRIP |
| L1,L2 | FERROXCUBE VK200-20/4B |
| C1,C3,C4,C6 | 1.0 μF TANTALUM 25 V |
| C2,C5 | 0.1 μF CERAMIC |
| R1 | 25-Ω Pot, 5 W, Linear Taper |

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FIGURE 2 – OUTPUT POWER, EFFICIENCY and VSWR versus FREQUENCY

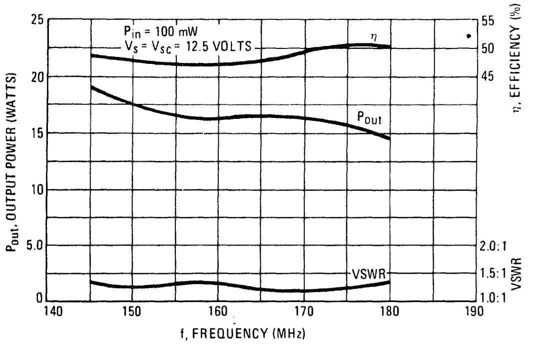



FIGURE 3 – OUTPUT POWER versus INPUT POWER

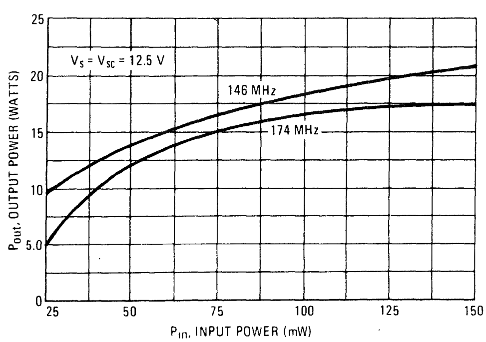



FIGURE 4 – OUTPUT POWER versus VOLTAGE

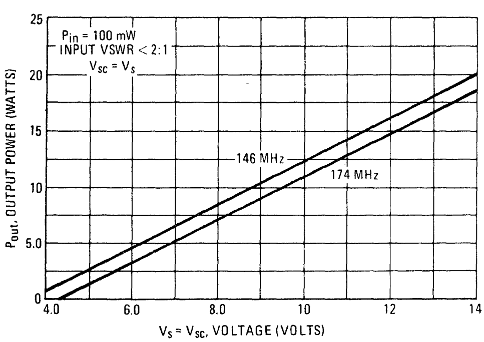



FIGURE 5 – GAIN CONTROL CURRENT versus CONTROL VOLTAGE

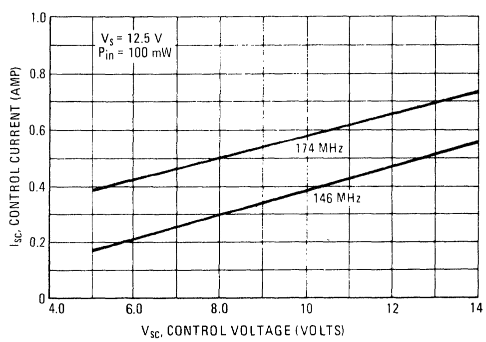



FIGURE 6 – OUTPUT POWER versus GAIN CONTROL VOLTAGE

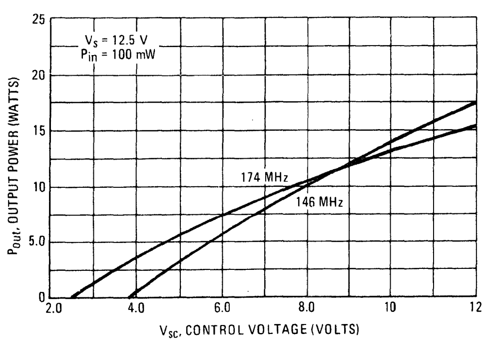


FIGURE 7 – TEST CIRCUIT

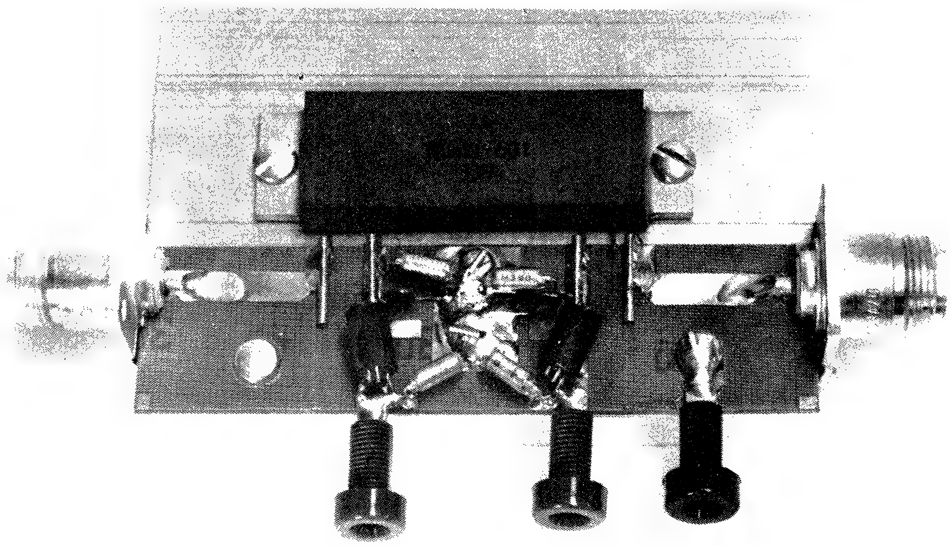
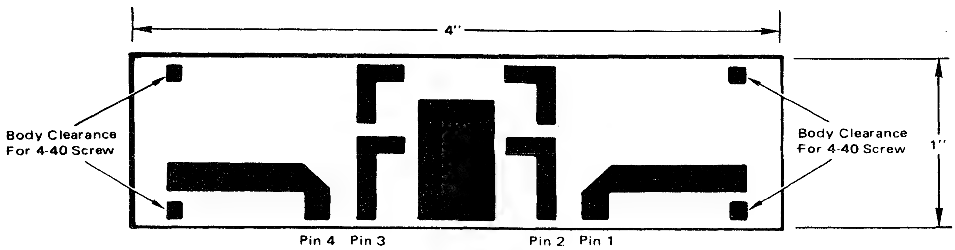


FIGURE 8 – VHF POWER MODULE TEST FIXTURE
PRINTED CIRCUIT BOARD




Teflon Glass Board
t = 0.062"
$\epsilon R$ = 2.56

Mount Board and module on 1/2" thick aluminum block for heat sinking and electrical ground. Pin 4 is not directly connected to ground in this test fixture. Ground is provided through module heat sink..

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# MHW602

## The RF Line

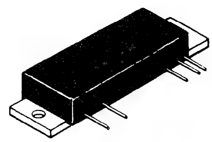
20 W – 174 MHz

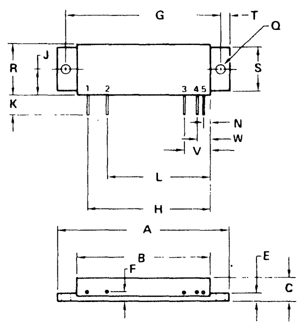
RF POWER
AMPLIFIER MODULE

### VHF POWER AMPLIFIER MODULE

. . . designed for 12.5 volt VHF power amplifier applications in industrial and commercial FM equipment operating to 174 MHz.

- Specified 12.5 Volt, 174 MHz Characteristics –
  Output Power = 20 Watts
  Minimum Gain = 20.6 dB
  Harmonic Content = -30 dB
- Frequency Range – 146 to 174 MHz
- Gain Control Pin for Constant Power Output Level






STYLE 1:
PIN 1. RF OUTPUT
2. D.C. TERM
3. D.C. GAIN
4. GROUND
5. RF INPUT

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 67.06 | 67.56 | 2.640 | 2.660 |
| B | 51.82 | 52.96 | 2.040 | 2.085 |
| C | 8.51 | 9.14 | 0.335 | 0.360 |
| E | 2.54 | 2.92 | 0.100 | 0.115 |
| F | 2.67 | 2.92 | 0.105 | 0.115 |
| G | 61.09 BSC | | 2.405 BSC | |
| H | 47.88 | 48.64 | 1.885 | 1.915 |
| J | 10.16 | 11.18 | 0.400 | 0.440 |
| K | 5.84 | 7.62 | 0.230 | 0.300 |
| L | 40.26 | 41.02 | 1.585 | 1.615 |
| N | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.45 | 3.71 | 0.136 | 0.146 |
| R | 20.32 | 20.83 | 0.800 | 0.820 |
| S | 17.02 | 17.53 | 0.670 | 0.690 |
| T | 2.98 | 3.24 | 0.1175 | 0.1275 |
| V | 9.78 | 10.54 | 0.385 | 0.415 |
| W | 4.70 | 5.46 | 0.185 | 0.215 |

CASE 297-02

### ELECTRICAL CHARACTERISTICS
($V_S$ and $V_{SC}$ @ 12.5 Vdc unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Frequency Range | – | 146 | 174 | MHz |
| Input Power ($P_{out}$ = 20 W) | $P_{in}$ | – | 175 | mW |
| Power Gain | $G_p$ | 20.6 | – | dB |
| Efficiency ($P_{out}$ = 20 W) | $\eta$ | 40 | – | % |
| Operating Voltage | – | – | 12.5 | Vdc |
| Harmonic Content ($P_{out}$ = 20 W, Reference) | – | – | -30 | dB |
| Input Impedance ($P_{out}$ = 20 W, 50 Ohm Reference) | $Z_{in}$ | – | 2.0:1 | VSWR |
| Power Degradation ($P_{out}$ = 20 W, $T_C$ = 25°C) ($T_C$ = 0°C to 60°C) | – | – | 0.3 | dB |
| Power Degradation ($P_{out}$ = 20 W, $T_C$ = 25°C) ($T_C$ = 0°C to 80°C) | – | – | 0.7 | dB |
| Load Mismatch (VSWR = ∞, $V_s$ = 15.5 Vdc, $P_{out}$ = 30 W) | – | No degradation in $P_{out}$ | | |
| Stability ($P_{in}$ = 10 to 350 mW, $V_s$ = 4.0 to 15 V, Load and Source Mismatch 4:1, 50 Ohm Reference, $V_s$ = 4.0 to 16 Vdc, $V_{sc}$ adjusted for $P_{out}$ = 8.0 to 28 W) | – | All spurious outputs more than 70 dB below desired signal | | |

## APPLICATIONS INFORMATION

**Nominal Operation**

All electrical specifications are based on the nominal conditions of Pin 3 voltage (control pin – $V_{SC}$) and Pin 2 voltage (main supply – $V_S$) equal 12.5 volts with output power equaling 20 watts. With these conditions, maximum current density on any device is $1.5 \times 10^5$ A/cm$^2$ and maximum die temperature with 100°C base plate temperature is 150°C. While the modules are designed to have excess gain margin with ruggedness, operation of these units outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

**Gain Control**

In general, the module output power should be limited to 25 watts. The preferred method of power output control is to fix both $V_{SC}$ and $V_S$ at 12.5 volts and to vary the input RF drive level at Pin 5. The next method is to control $V_{SC}$ through a stiff voltage source.

A third method of power output control is to control $V_{SC}$ through a current source or voltage source with series resistance. This mode of control creates a region of negative slope on the power gain profile curve and aggravates output power slump with temperature.

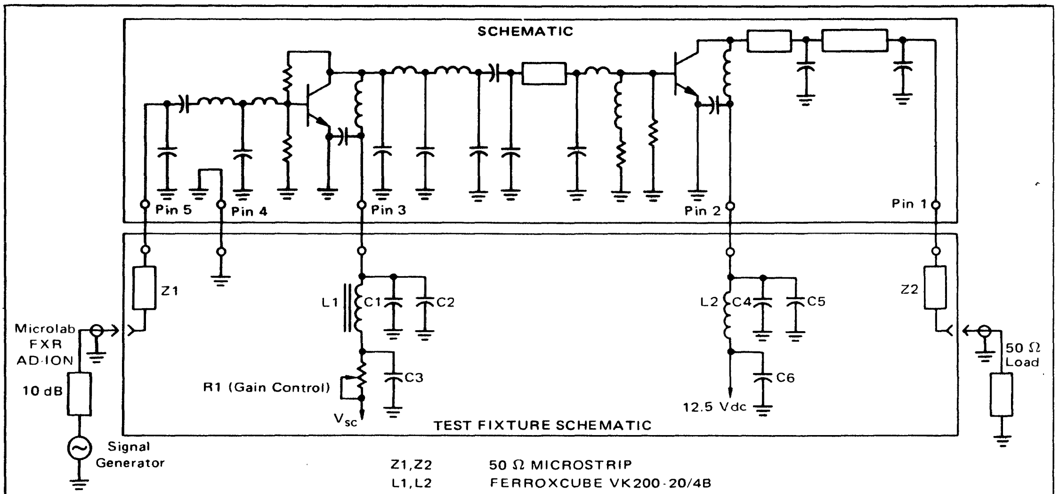
**Decoupling**

Due to the high gain of each of the two stages and the module size limitation, external decoupling networks require careful consideration. Both Pins 2 and 3 are internally bypassed with an 0.018 mF chip capacitor effective for frequencies of 5 MHz through 174 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic are recommended. Inadequate decoupling will result in spurious outputs at specific operating frequencies and phase angles of input and output VSWR less than 4:1.

**Load Pull**

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrical conditions are $V_S$ and $V_{SC}$ equal to 15.5 volts output, VSWR 20:1, and output power equal to 30 watts.

FIGURE 1 – VHF MODULE TEST SET UP




| | |
|---|---|
| Z1,Z2 | 50 Ω MICROSTRIP |
| L1,L2 | FERROXCUBE VK200-20/4B |
| C1,C3,C4,C6 | 1.0 μF TANTALUM 25 V |
| C2,C5 | 0.1 μF CERAMIC |
| R1 | 25-Ω Pot, 5 W, Linear Taper |

FIGURE 2 – OUTPUT POWER, EFFICIENCY and VSWR versus FREQUENCY

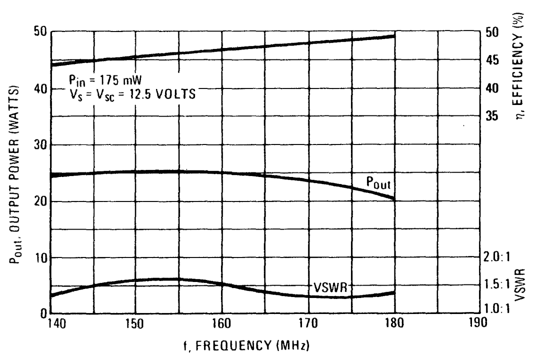



FIGURE 3 – OUTPUT POWER versus INPUT POWER

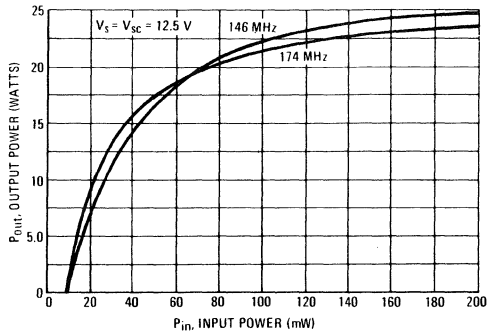



FIGURE 4 – OUTPUT POWER versus VOLTAGE

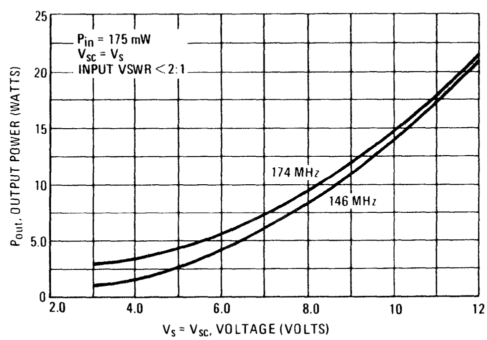



FIGURE 5 – GAIN CONTROL CURRENT versus CONTROL VOLTAGE

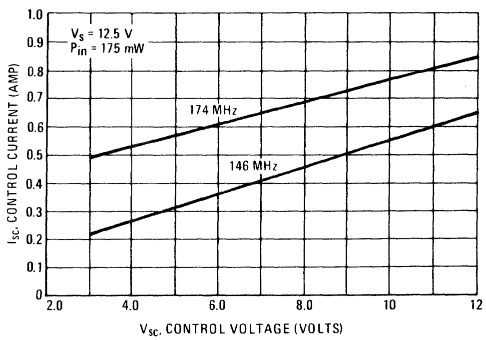



FIGURE 6 – OUTPUT POWER versus GAIN CONTROL VOLTAGE

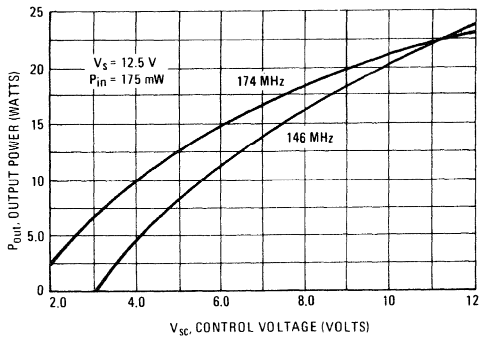


FIGURE 7 – TEST CIRCUIT

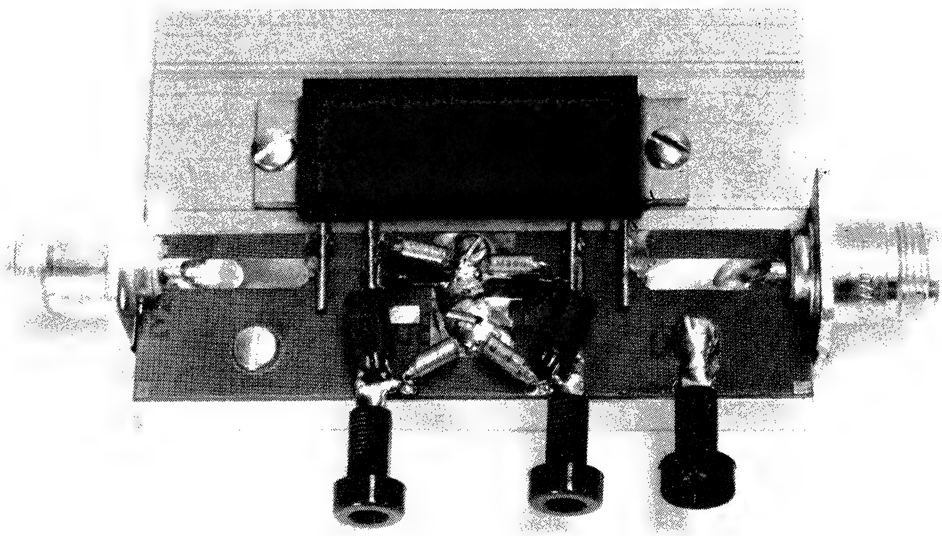
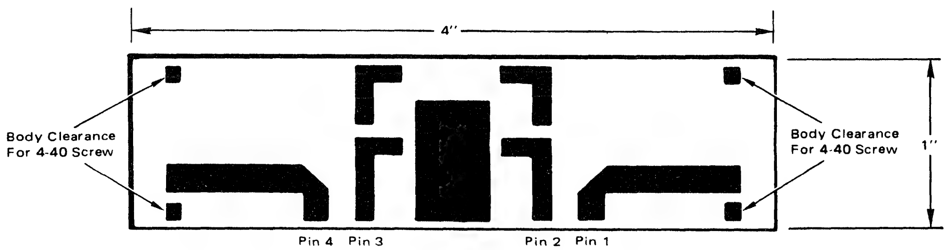


FIGURE 8 – VHF POWER MODULE TEST FIXTURE
PRINTED CIRCUIT BOARD




Teflon Glass Board
$t = 0.062''$
$\epsilon_R = 2.56$

Mount Board and module on 1/2" thick aluminum block for heat sinking and electrical ground. Pin 4 is not directly connected to ground in this test fixture. Ground is provided through module heat sink.

MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MHW603

## The RF Line

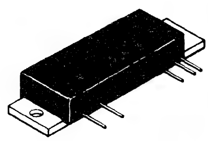
### VHF POWER AMPLIFIER MODULE

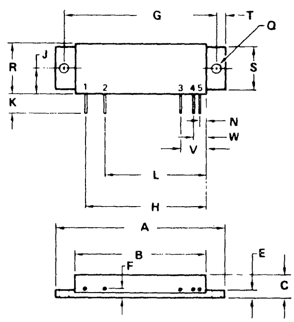
. . . designed for 13.6 volt VHF power amplifier applications in industrial and commercial FM equipment operating in the 160 MHz marine band.

- Specified 13.6 Volt, 160 MHz Characteristics –
  Output Power = 30 Watts
  Minimum Gain = 21.7 dB
  Harmonic Content = -30 dB
- Frequency – 160 MHz
- Gain Control Pin for Constant Power Output Level

**30 W – 160 MHz**

**RF BROADBAND POWER AMPLIFIER MODULE**






STYLE 1
PIN 1. RF OUTPUT
2. D.C. TERM
3. D.C. GAIN
4. GROUND
5. RF INPUT

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 67.06 | 67.56 | 2.640 | 2.660 |
| B | 51.82 | 52.96 | 2.040 | 2.085 |
| C | 8.51 | 9.14 | 0.335 | 0.360 |
| E | 2.54 | 2.92 | 0.100 | 0.115 |
| F | 2.67 | 2.92 | 0.105 | 0.115 |
| G | 61.09 BSC | | 2.405 BSC | |
| H | 47.88 | 48.64 | 1.885 | 1.915 |
| J | 10.16 | 11.18 | 0.400 | 0.440 |
| K | 5.84 | 7.62 | 0.230 | 0.300 |
| L | 40.26 | 41.02 | 1.585 | 1.615 |
| N | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.45 | 3.71 | 0.136 | 0.146 |
| R | 20.32 | 20.83 | 0.800 | 0.820 |
| S | 17.02 | 17.53 | 0.670 | 0.690 |
| T | 2.98 | 3.24 | 0.1175 | 0.1275 |
| V | 9.78 | 10.54 | 0.385 | 0.415 |
| W | 4.70 | 5.46 | 0.185 | 0.215 |

CASE 297-02

### ELECTRICAL CHARACTERISTICS
($V_S$ and $V_{SC}$ @ 13.6 Vdc unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Input Power ($P_{out}$ = 30 W, f = 160 Mhz) | $P_{in}$ | – | 200 | mW |
| Power Gain | $G_p$ | 21.7 | – | dB |
| Efficiency (1) ($P_{out}$ = 30 W, f = 160 MHz, $V_s$ = 13.6 Vdc) | $\eta$ | 45 | – | % |
| Operating Voltage | – | – | 13.6 | Vdc |
| Harmonic Content (1) ($P_{out}$ = 30 W, f = 160 MHz, $V_s$ = 13.6 Vdc) | – | – | -30 | dB |
| Input Impedance (1) ($P_{out}$ = 30 W, 50 Ohm Reference, f = 160 MHz, $V_s$ = 13.6 Vdc) | $Z_{in}$ | – | 2.0:1 | VSWR |
| Power Degradation (1) ($P_{out}$ = 30 W, $T_C$ = 25°C) ($T_C$ = 0°C to 60°C, f = 160 MHz, $V_s$ = 13.6 Vdc) | – | – | 0.3 | dB |
| Power Degradation (1) ($P_{out}$ = 30 W, $T_C$ = 25°C) ($T_C$ = 0°C to 80°C, f = 160 MHz, $V_s$ = 13.6 Vdc) | – | – | 0.7 | dB |
| Load Mismatch (VSWR = 30:1, $V_s$, $V_{sc}$ = 16 Vdc, $P_{out}$ = 40 W) | – | No degradation in $P_{out}$ | | |
| Stability ($P_{in}$ = 50 to 250 mW, $V_s$ = 8.0 to 16 V, Load and Source Mismatch 4:1, 50 Ohm Reference, $V_s$ = 8.0 to 16 Vdc, $V_{sc}$ adjusted for $P_{out}$ = 5.0 to 30 W) | – | All spurious outputs more than 70 dB below desired signal | | |

(1) $P_{in}$ = 200 mW, $V_{sc}$ Adjusted for 30 Watts Output.

## APPLICATIONS INFORMATION

### Nominal Operation

All electrical specifications are based on the following nominal conditions: ($P_{in}$ = 200 mW, $V_s$ = 13.6 V, $V_{sc}$ adjusted for 30 W $P_{out}$). These modules are designed to have excess gain margin with ruggedness, operation outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

### Gain Control

In general, the module output power should be limited to 35 watts. The preferred method of power output control is to fix both $V_{sc}$ and $V_s$ at 13.6 volts and to vary the input RF drive level at Pin 5. The next method is to control $V_{sc}$ through a stiff voltage source.

A third method of power output control is to control $V_{sc}$ through a current source or voltage source with series resistance. This mode of control creates a region of negative slope on the power gain profile curve and aggravates output power slump with temperature.

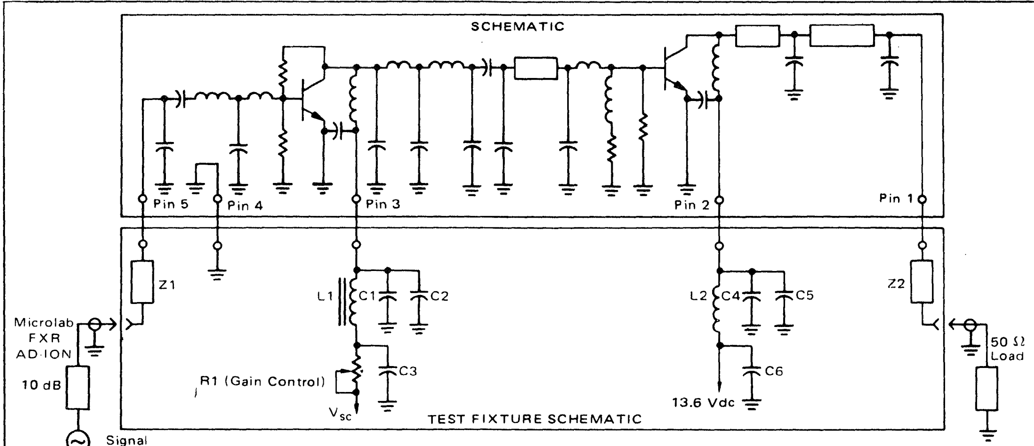
### Decoupling

Due to the high gain of each of the two stages and the module size limitation, external decoupling networks require careful consideration. Both Pins 2 and 3 are internally bypassed with a 0.018 μF chip capacitor effective for frequencies of 5 MHz through 174 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic are recommended. Inadequate decoupling will result in spurious outputs at specific operating frequencies and phase angles of input and output VSWR less than 4:1.

### Load Pull

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrical conditions are $V_s$ and $V_{sc}$ equal to 16 volts output, VSWR 30:1 and output power equal to 40 watts.

FIGURE 1 – VHF MODULE TEST SET UP




| | |
|---|---|
| Z1, Z2 | 50 Ω MICROSTRIP |
| L1, L2 | FERROXCUBE VK200 20/4B |
| C1, C3, C4, C6 | 1.0 μF TANTALUM 25 V |
| C2, C5 | 0.1 μF CERAMIC |
| R1 | 25-Ω Pot, 5 W, Linear Taper |

FIGURE 2 – OUTPUT POWER versus INPUT POWER

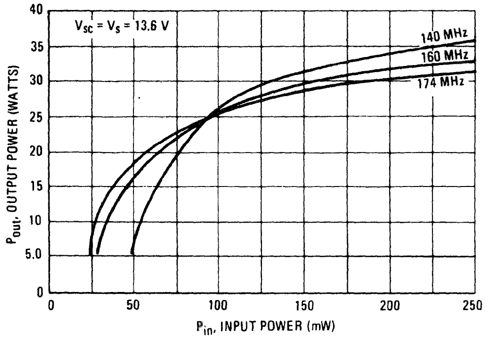



FIGURE 3 – OUTPUT POWER, EFFICIENCY AND INPUT RETURN LOSS versus FREQUENCY

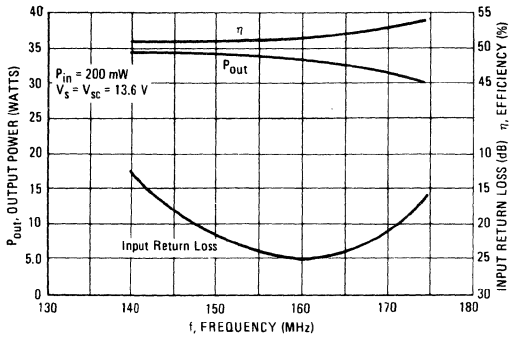



FIGURE 4 – OUTPUT POWER versus VOLTAGE

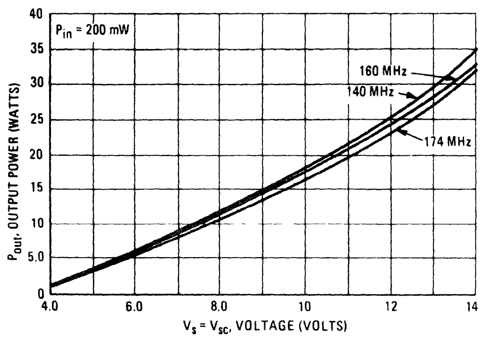



FIGURE 5 – OUTPUT POWER versus CONTROL VOLTAGE

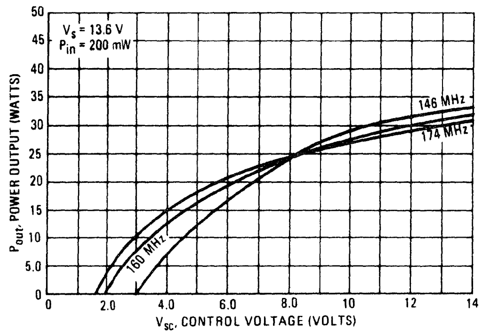


FIGURE 6 – TEST CIRCUIT

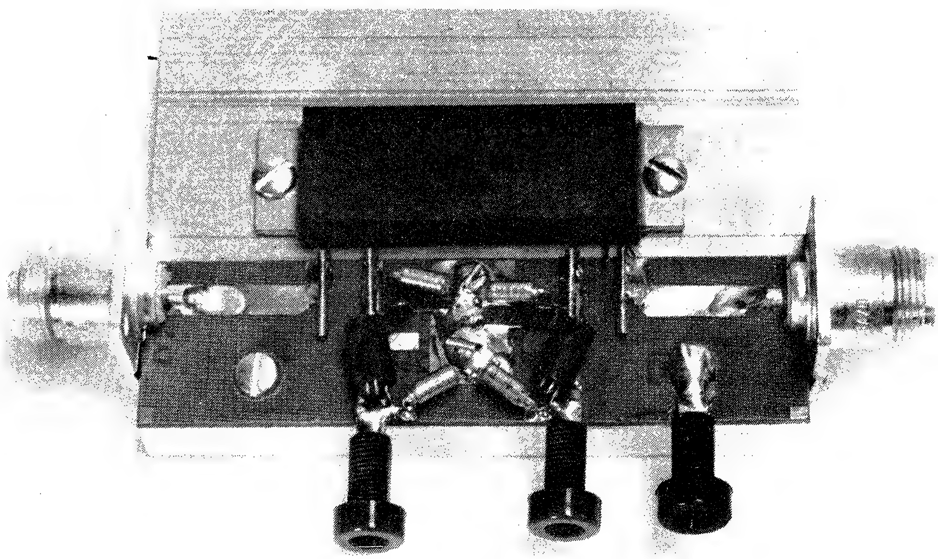
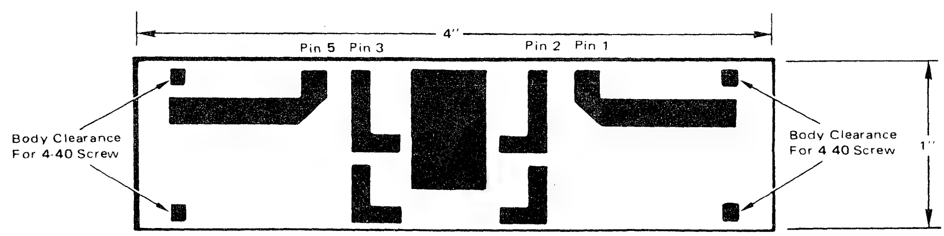


FIGURE 7 – VHF POWER MODULE TEST FIXTURE PRINTED CIRCUIT BOARD




Teflon Glass Board
t = 0.062''
$\epsilon_R$ = 2.56

Mount Board and module on 1/2'' thick aluminum block for heat sinking and electrical ground. Pin 4 is not directly connected to ground in this test fixture. Ground is provided through module heat sink.

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BOX 20912 • PHOENIX, ARIZONA 85036

# MHW709

## The RF Line

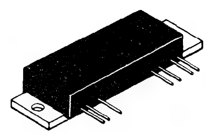
7.5 W – 400-512 MHz

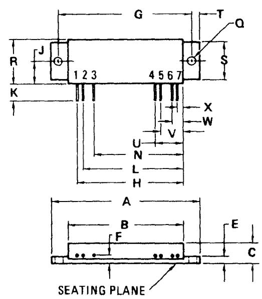
RF POWER
AMPLIFIER MODULE

### UHF POWER AMPLIFIER MODULE

. . . designed for 12.5 volt UHF power amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, UHF Characteristics –
  - Output Power = 7.5 Watts
  - Minimum Gain = 18.8 dB
  - Harmonics = -40 dB
- Frequency Range – 400 to 512 MHz
- Gain Control Pin for Constant Output Power Level






| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 67.06 | 67.56 | 2.640 | 2.660 |
| B | 51.82 | 52.96 | 2.040 | 2.085 |
| C | 8.51 | 9.14 | 0.335 | 0.360 |
| E | 2.54 | 2.92 | 0.100 | 0.115 |
| F | 2.67 | 2.92 | 0.105 | 0.115 |
| G | 61.09 BSC | | 2.405 BSC | |
| H | 47.88 | 48.64 | 1.885 | 1.915 |
| J | 10.16 | 11.18 | 0.400 | 0.440 |
| K | 5.84 | 7.62 | 0.230 | 0.300 |
| L | 45.34 | 46.10 | 1.785 | 1.815 |
| N | 40.26 | 41.02 | 1.585 | 1.615 |
| Q | 3.45 | 3.71 | 0.136 | 0.146 |
| R | 20.32 | 20.83 | 0.800 | 0.820 |
| S | 17.02 | 17.53 | 0.670 | 0.690 |
| T | 2.98 | 3.24 | 0.1175 | 0.1275 |
| U | 12.32 | 13.08 | 0.485 | 0.515 |
| V | 9.78 | 10.54 | 0.385 | 0.415 |
| W | 4.70 | 5.46 | 0.185 | 0.215 |
| X | 2.16 | 2.92 | 0.085 | 0.115 |

STYLE 1:
PIN 1. RF OUTPUT
2. GROUND
3. D.C. TERMINAL
4. GROUND
5. D.C. GAIN
6. GROUND
7. RF INPUT

CASE 700-03

**ELECTRICAL CHARACTERISTICS** ($V_S$ and $V_{SC}$ set at 12.5 Vdc unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Frequency Range[1] | – | 400 | 512 | MHz |
| Input Power ($P_{out}$ = 7.5 W) | $P_{in}$ | – | 100 | mW |
| Power Gain | $G_p$ | 18.8 | – | dB |
| Efficiency ($P_{out}$ = 7.5 W) | $\eta$ | 35 | – | % |
| Harmonics ($P_{out}$ = 7.5 W, Reference) | – | – | -40 | dB |
| Input Impedance ($P_{out}$ = 7.5 W, 50 Ω Reference) | $Z_{in}$ | – | 2:1 | VSWR |
| Power Degradation ($P_{out}$ = 7.5 W, $T_C$ = 25°C) ($T_C$ ·0°C to 60°C) | – | – | 0.3 | dB |
| Power Degradation ($P_{out}$ = 7.5 W, $T_C$ = 25°C) ($T_C$ = 0°C to 80°C) | – | – | 0.7 | dB |
| Load Mismatch (VSWR = ∞, $V_s$ = 15.5 Vdc, $P_{out}$ = 10 W) | – | No degradation in $P_{out}$ | | |
| Stability ($P_{in}$ = 30 to 150 mW, Load Mismatch 2:1, 50 Ω reference, $V_s$ = 8.0 to 16 Vdc, $V_{sc}$ adjusted for $P_{out}$ = 5.0 to 12 W) | – | All spurious outputs more than 70 dB below desired signal. | | |

(1) Frequency Range is covered in three bands:
MHW709-1 400-440 MHz
MHW709-2 440-470 MHz
MHW709-3 470-512 MHz

## APPLICATIONS INFORMATION

### Nominal Operation

All electrical specifications are based on the nominal conditions Pin 5 voltage (control pin – $V_{SC}$) and Pin 3 voltage (main supply – $V_S$) equal 12.5 Vdc and with output power equaling 7.5 watts. With these conditions, maximum current density on any device is $1.5 \times 10^5$ A/cm$^2$ and maximum die temperature with 100° base plate temperature is 165°. While the modules are designed to have excess gain margin with ruggedness, operation of these units outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

### Gain Control

In general, the module output power should be limited to 7.5 watts. The preferred method of power output control is to fix both $V_{SC}$ and $V_S$ at 12.5 Vdc and vary the input RF drive level at Pin 7. The next method is to control $V_{SC}$ through a stiff voltage source.

A third method of power output control is to control $V_{SC}$ through a current source or voltage source with series resistance. This mode of control creates a region of negative slope on the power gain profile curve and aggravates output power slump with temperature.

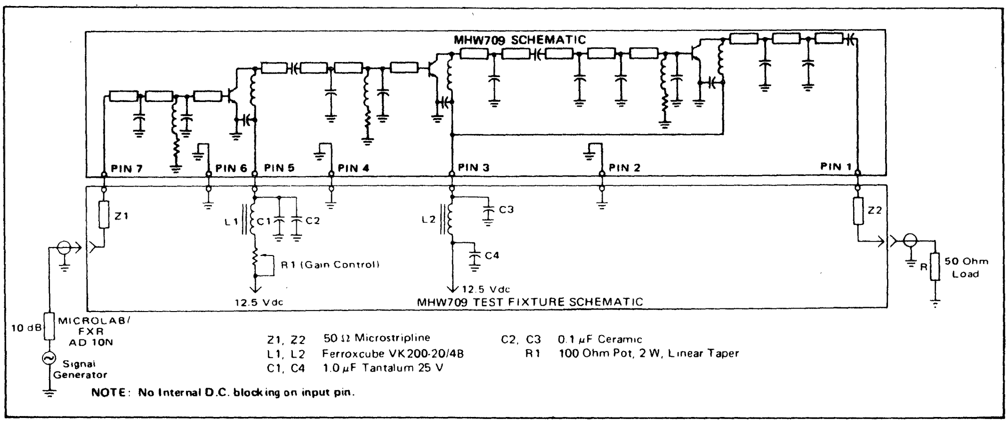
### Decoupling

The high gain of the three stages and the module size limitation, external decoupling network requires careful consideration. Both Pins 3 and 5 are internally bypassed with a 0.018 mF chip capacitor effective for frequencies from 5 through 512 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic is recommended. Inadequate decoupling will result in spurious outputs at certain operating frequencies and certain phase angles of input and output VSWR less than 3:1.

### Load Pull

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrical conditions are $V_S$ and $V_{SC}$ equal 15.5 V output, VSWR infinite, output power equal to 10 watts.

FIGURE 1 – UHF POWER MODULE TEST SETUP



## TYPICAL PERFORMANCE CURVES
(MHW709-2)

**FIGURE 2 – INPUT POWER, EFFICIENCY, AND VSWR versus FREQUENCY**

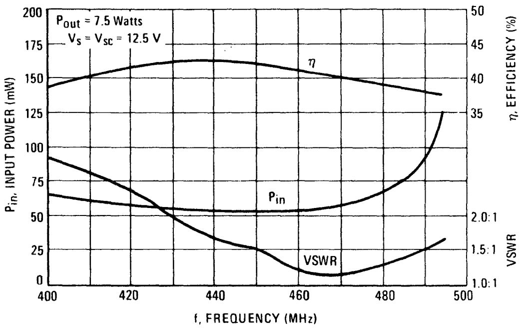



**FIGURE 3 – OUTPUT POWER versus INPUT POWER**

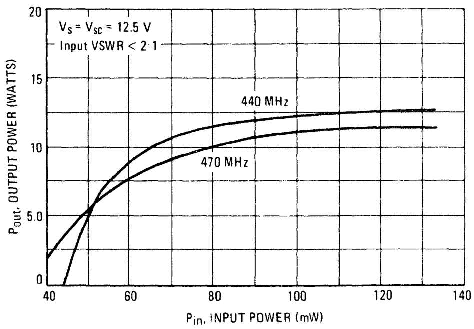



**FIGURE 4 – OUTPUT POWER versus VOLTAGE**

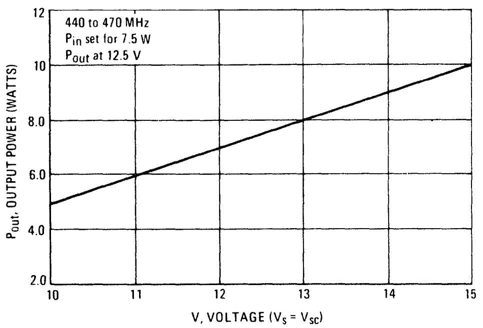



**FIGURE 5 – OUTPUT POWER versus GAIN CONTROL VOLTAGE**

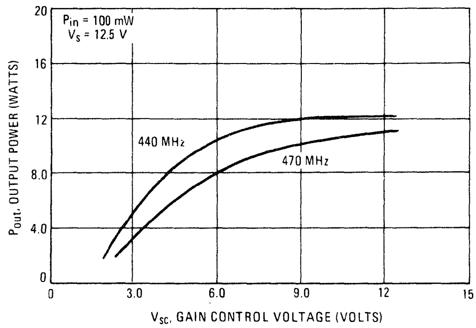



**FIGURE 6 – GAIN CONTROL CURRENT versus VOLTAGE**

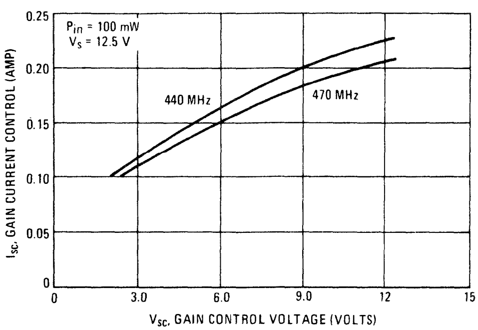


FIGURE 7 – TEST CIRCUIT

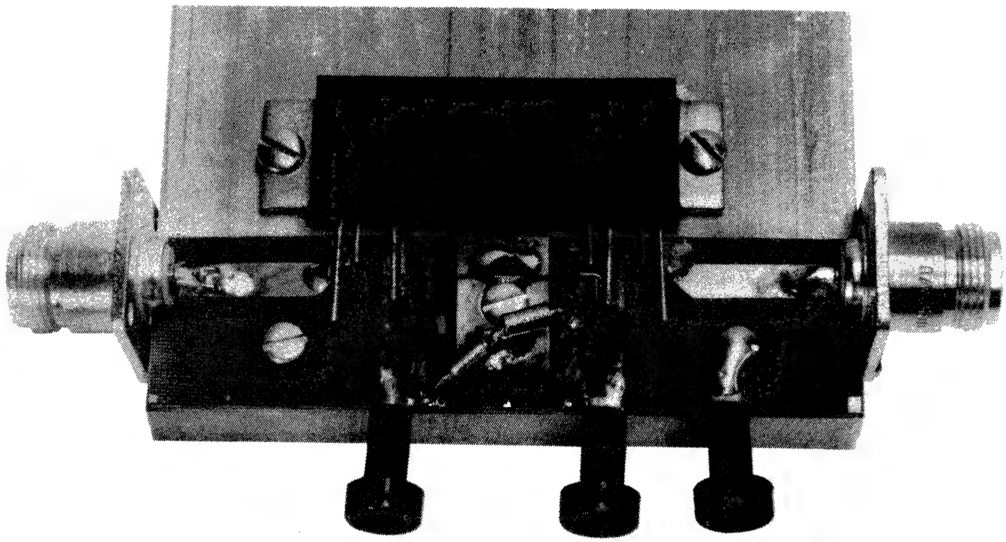
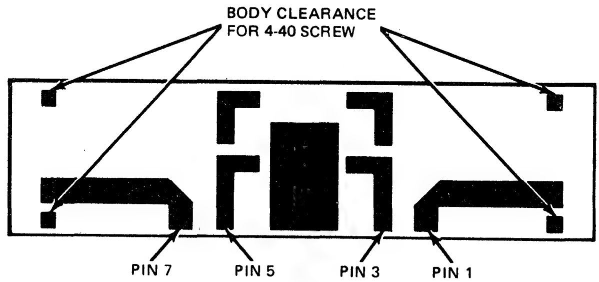


FIGURE 8 – UHF POWER MODULE TEST FIXTURE
PRINTED CIRCUIT BOARD




Teflon Glass Board
t = 0.062″
$\epsilon_R = 2.56$

NOTE:
Mount board and module on 1/2″ thick aluminum block for heat sinking and electrical ground. Pins 2, 4 and 6 are not directly connected to ground in this test fixture. Ground is provided through module heat sink.

**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

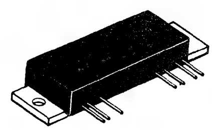
# MHW710

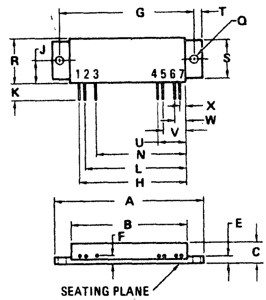
## The RF Line

**13 W – 400-512 MHz**

**RF POWER**

**AMPLIFIER MODULE**






| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 67.06 | 67.56 | 2.640 | 2.660 |
| B | 51.82 | 52.96 | 2.040 | 2.085 |
| C | 8.51 | 9.14 | 0.335 | 0.360 |
| E | 2.54 | 2.92 | 0.100 | 0.115 |
| F | 2.67 | 2.92 | 0.105 | 0.115 |
| G | 61.09 BSC | | 2.405 BSC | |
| H | 47.88 | 48.64 | 1.885 | 1.915 |
| J | 10.16 | 11.18 | 0.400 | 0.440 |
| K | 5.84 | 7.62 | 0.230 | 0.300 |
| L | 45.34 | 46.10 | 1.785 | 1.815 |
| N | 40.26 | 41.02 | 1.585 | 1.615 |
| Q | 3.45 | 3.71 | 0.136 | 0.146 |
| R | 20.32 | 20.83 | 0.800 | 0.820 |
| S | 17.02 | 17.53 | 0.670 | 0.690 |
| T | 2.98 | 3.24 | 0.1175 | 0.1275 |
| U | 12.32 | 13.08 | 0.485 | 0.515 |
| V | 9.78 | 10.54 | 0.385 | 0.415 |
| W | 4.70 | 5.46 | 0.185 | 0.215 |
| X | 2.16 | 2.92 | 0.085 | 0.115 |

STYLE 1:
PIN 1. RF OUTPUT
2. GROUND
3. D.C. TERMINAL
4. GROUND
5. D.C. GAIN
6. GROUND
7. RF INPUT

CASE 700-03

### UHF POWER AMPLIFIER MODULE

. . . designed for 12.5 volt UHF power amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

- Specified 12.5 Volt, UHF Characteristics –
  Output Power = 13 Watts
  Minimum Gain = 19.4 dB
  Harmonics = -40 dB
- Frequency Range – 400 to 512 MHz
- Gain Control Pin for Constant Output Power Level

**ELECTRICAL CHARACTERISTICS** ($V_s$ and $V_{sc}$ set at 12.5 Vdc unless otherwise noted.)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Frequency Range (1) | – | 400 | 512 | MHz |
| **Input Power** ($P_{out}$ = 13 W) | $P_{in}$ | – | 150 | mW |
| Power Gain | $G_p$ | 19.4 | – | dB |
| Efficiency ($P_{out}$ = 13 W) | $\eta$ | 35 | – | % |
| Harmonics ($P_{out}$ = 13 W, Reference) | – | – | –40 | dB |
| Input Impedance ($P_{out}$ = 13 W, 50 Ohm Reference) | $Z_{in}$ | – | 2:1 | VSWR |
| Power Degradation ($P_{out}$ = 13 W, $T_C$ = 25°C) ($T_C$ = 0°C to 60°C) | – | – | 0.3 | dB |
| Power Degradation ($P_{out}$ = 13 W, $T_C$ = 25°C) ($T_C$ = 0°C to 80°C) | – | – | 0.7 | dB |
| Load Mismatch (VSWR = ∞, $V_s$ = 15.5 Vdc, $P_{out}$ = 16.5 W) | – | No degradation in $P_{out}$ | | |
| Stability ($P_{in}$ = 50 to 200 mW, Load Mismatch 2:1 50 ohm reference, $V_s$ = 8.0 to 16 Vdc, $V_{sc}$ adjusted for $P_{out}$ = 5.0 to 16 W) | – | All spurious outputs more than 70 dB below desired signal. | | |

**(1) Frequency Range is covered in three bands:**
MHW710-1 400-440 MHz
MHW710-2 440-470 MHz
**MHW710-3 470-512 MHz**

## APPLICATIONS INFORMATION

### Nominal Operation

All electrical specifications are based on the nominal conditions Pin 5 voltage (control pin – $V_{SC}$) and Pin 3 voltage (main supply – $V_S$) equal 12.5 Vdc and with output power equaling 13 watts. With these conditions, maximum current density on any device is $1.5 \times 10^5$ A/cm$^2$ and maximum die temperature with 100$^o$ base plate temperature is 165$^o$. While the modules are designed to have excess gain margin with ruggedness, operation of these units outside the limits of published specifications is not recommended unless prior communications regarding intended use has been made with the factory representative.

### Gain Control

In general, the module output power should be limited to 13 watts. The preferred method of power output control is to fix both $V_{SC}$ and $V_S$ at 12.5 Vdc and vary the input RF drive level at Pin 7. The next method is to control $V_{SC}$ through a stiff voltage source.

A third method of power output control is to control $V_{SC}$ through a current source or voltage source with series resistance. This mode of control creates a region of negative slope on the power gain profile curve and aggravates output power slump with temperature.

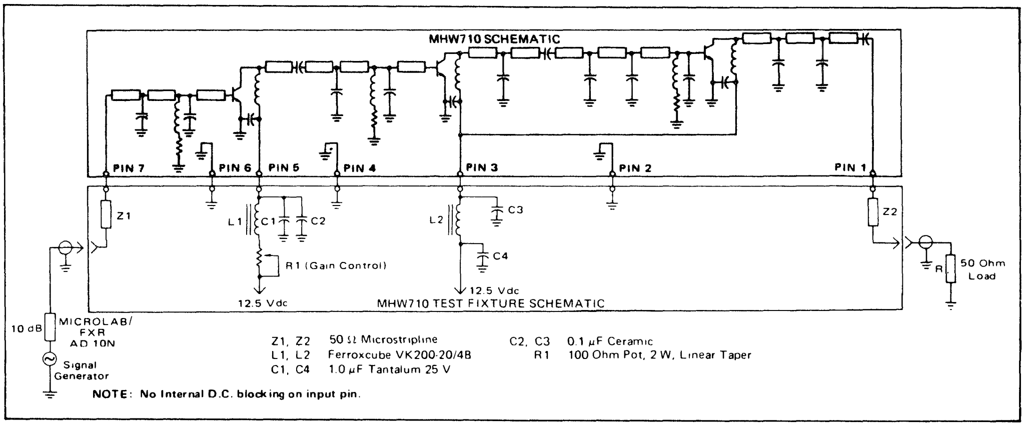
### Decoupling

The high gain of the three stages and the module size limitation, external decoupling network requires careful consideration. Both Pins 3 and 5 are internally bypassed with a 0.018 mF chip capacitor effective for frequencies from 5 through 512 MHz. For bypassing frequencies below 5 MHz, networks equivalent to that shown in the test figure schematic is recommended. Inadequate decoupling will result in spurious outputs at certain operating frequencies and certain phase angles of input and output VSWR less than 3:1.

### Load Pull

During final test, each module is "load pull" tested in a fixture having the identical decoupling network described in Figure 1. Electrical conditions are $V_S$ and $V_{SC}$ equal 15.5 V output, VSWR infinite, output power equal to 16.5 watts.

FIGURE 1 – UHF POWER MODULE TEST SETUP



## TYPICAL PERFORMANCE CURVES

(MHW710-2)

**FIGURE 2 – INPUT POWER, EFFICIENCY, AND VSWR versus FREQUENCY**

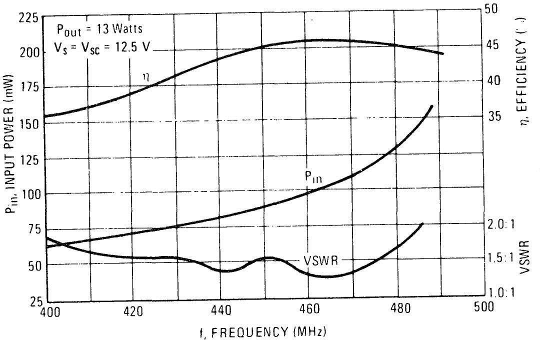



**FIGURE 3 – OUTPUT POWER versus INPUT POWER**

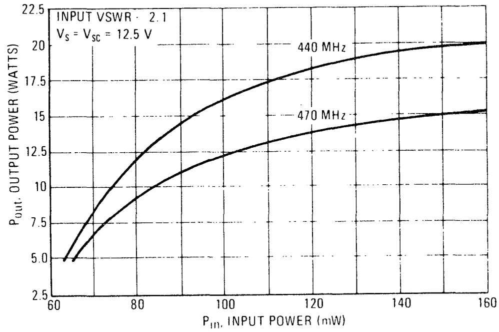



**FIGURE 4 – OUTPUT POWER versus VOLTAGE**

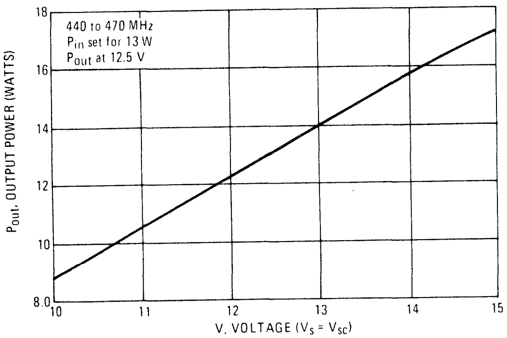



**FIGURE 5 – OUTPUT POWER versus GAIN CONTROL VOLTAGE**

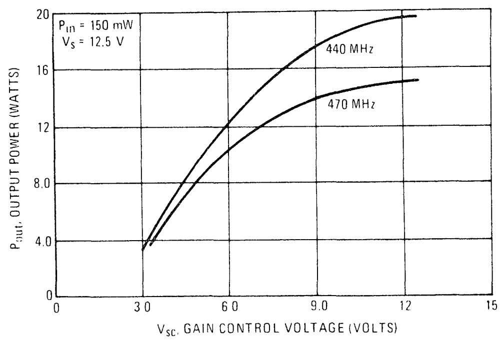



**FIGURE 6 – GAIN CONTROL CURRENT versus VOLTAGE**

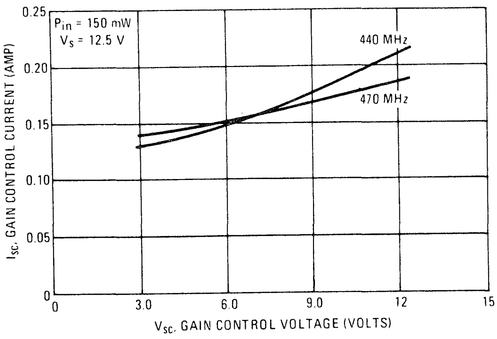


FIGURE 7 – TEST CIRCUIT

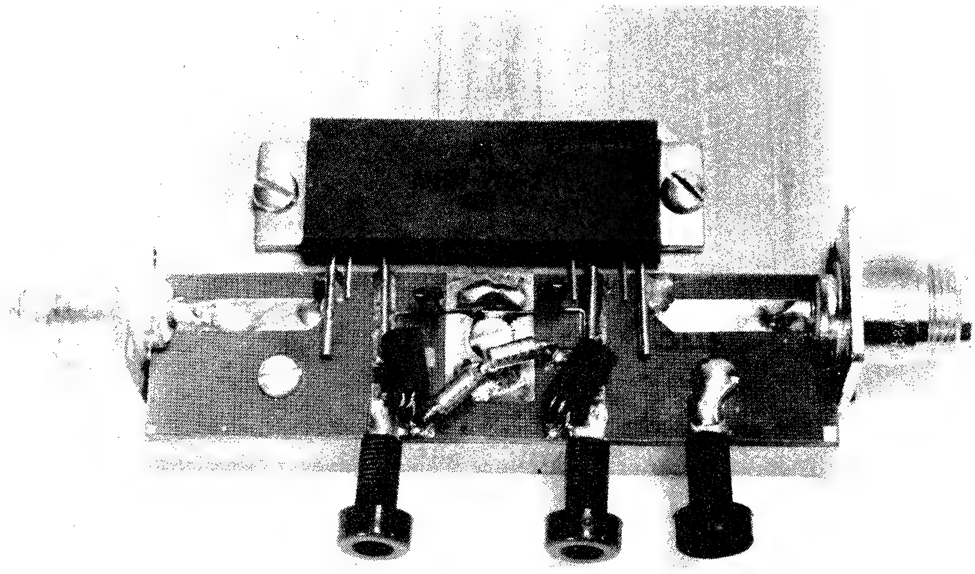
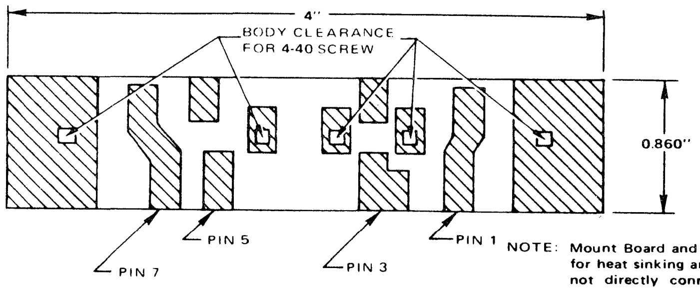


FIGURE 8 – UHF POWER MODULE TEST FIXTURE
PRINTED CIRCUIT BOARD

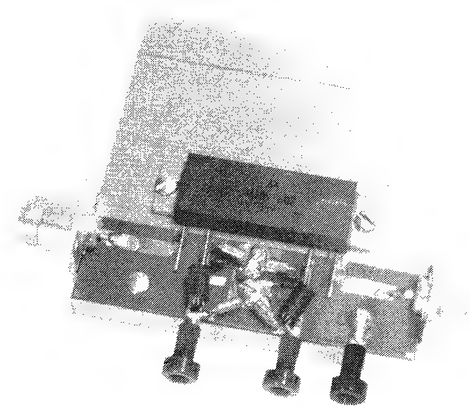



Teflon Glass Board
$t = 0.062''$
$\epsilon_R = 2.56$

NOTE: Mount Board and module on 1/2" thick aluminum block for heat sinking and electrical ground. Pins 2, 4 and 6 are not directly connected to ground in this test fixture. Ground is provided through module heat sink.

# How To Apply The MHW601/602 VHF Power Modules

**VHF Power Module Test Information**
**(MHW601 AND MHW602)**



TEST CIRCUIT

Motorola's VHF Power Modules use thin film construction to minimize parasitics, and for manufacturing consistency. They're flange mount for easy, one-sided assembly. They reduce your system inventory, eliminate the need for special production equipment. But even though the MHW601/MHW602 are "complete" VHF power drivers and reduce RF design and production to a new level of ease, there are a few operation and testing considerations to follow for best results.

The modules are conservatively rated. Actual output power capability is 50 to 70% above rated power. However, the equipment designer should not design a product using the module above the rated output power. In some cases, if smaller margins are acceptable and certain other conditions are met, some of the reserve power output can be used. In this case, please contact your Motorola representative for specific recommendations.

When operated within published specifications, the maximum device current density seen in a limit module will be $1.5 \times 10^5$ A/cm$^2$. Maximum die temperature with a 100°C base plate temperature will be 150°C.

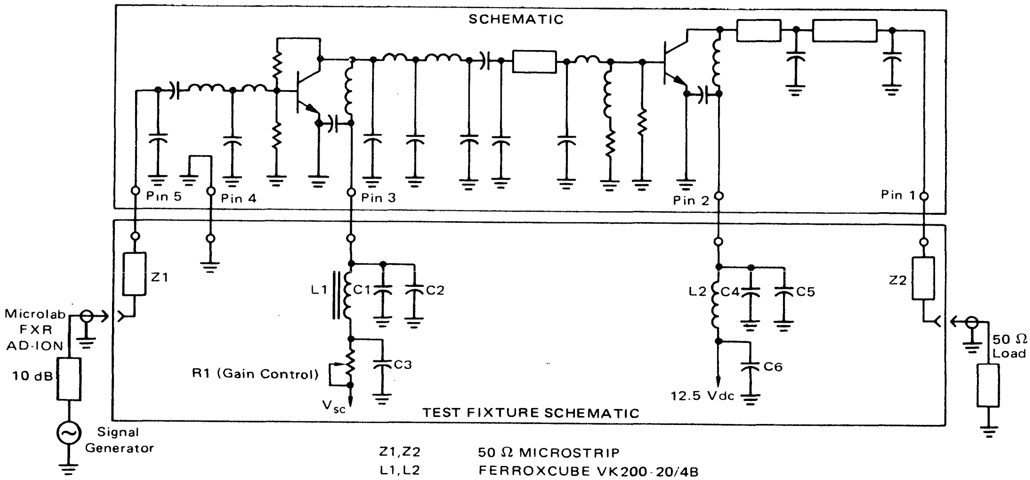
Nominal ratings are for a 12.5 Vdc supply ($V_S$ at pin 2) and control ($V_{SC}$ at pin 3) voltage. Specifications such as power gain, efficiency, and input VSWR are measured with the nominal 12.5 Vdc supply and an output power of 13 W (MHW601) and 20 W (MHW602).

**Gain Control**

The preferred method of operation is to apply 12.5 Vdc to both pin 3 and pin 2 through the recommended decoupling network. (In general, the module output power should be limited to 15 W, MHW601; 24 W, MHW602.) The output of the module is then set by adjusting the input drive level. Operation in this manner will result in the best performance with temperature variation.

Pin 3 supplies collector voltage to the input stage in the module. This pin is internally bypassed by a .018 μF chip capacitor effective for frequencies from 5-MHz through the operating frequency. Due to size limitations in the module, additional external low frequency decoupling effective below 5 MHz is required (as is required with discrete VHF transistors). If pin 3 is used to reduce the module output, two characteristics may cause an application problem.

**FIGURE 1 — VHF MODULE TEST SET UP**




| | |
|---|---|
| Z1,Z2 | 50 Ω MICROSTRIP |
| L1,L2 | FERROXCUBE VK200-20/4B |
| C1,C3,C4,C6 | 1.0 μF TANTALUM 25 V |
| C2,C5 | 0.1 μF CERAMIC |
| R1 | 25-Ω Pot, 5 W, Linear Taper |

One is that with the drive power appreciably above that required (+2 dB or so) for 13 watts output, the voltage on the first stage may be as low as four or five volts. This low voltage tends to increase the slump in output power with increasing temperature as opposed to the condition of pin 3 = pin 2 = 12.5 V and drive adjusted for desired power output. Second, if voltage to pin 3 is derived from a series dropping resistor and the value of the resistor is above 10 or 20 ohms, the output power will tend to rise with decreasing drive which could cause problems in an application using an automatic gain or output leveling circuit. If pin 5 is fed from a regulated voltage source, as opposed to a series dropping resistor, this problem does not arise; however, the temperature slump characteristic is still present.

Typically, the MHW602 slump at 80°C from rated output at 25°C with V3 = V2 = 12.5 Vdc is 9 to 12%. With pin 3 voltage set for rated output power and rated drive applied, the typical slump will be 10 to 16% at 80°C. Slump in the MHW601 under the same conditions is typically 5% less than the above figures.

**Decoupling**

As mentioned, size limitations in the module make it necessary to provide external decoupling for frequencies below 5 or 10 MHz. This can take the form of a network as shown on the data sheet. All decoupling capacitors internal to the module are .018 μF chips. Interstage blocking capacitors are 120 pF NPO chips. This chip type has a nominal reactance of 9 ohms in the VHF band and was selected to decrease the module gain at frequencies below the pass band. Also, the base return chokes in all stages were selected to degrade gain slightly at VHF with greater effect at lower frequencies. The use of small coupling and blocking capacitors along with low impedance base returns reduces the loop gain at low frequencies to minimize low frequency problems from the increased device gains below the operating frequency.

The decoupling network shown on the data sheet is used during final test of the module and has been found effective for our test setup. Differences in test circuit layout, ground current paths or other low frequency feedback circuits could require a modified decoupling network. Some applications may benefit from the use of a series R-C damping circuit connected to ground from pins 2 or 1. This can consist of a 5 to 10 ohm carbon resistor in series with a 1 to 10 μF, 25 volt electrolytic or tantalum capacitor.

**Source and Load Impedances**

The modules are designed for proper operation with source and load impedances of 50 ohms resistive. With proper decoupling, they will be stable with 4:1 VSWR source and load impedances, any phase angle and any combination of phase angles at nominal drive and power output. In addition, the rf drive and supply voltage can be varied over wide ranges. Typically, during this test, no spurious outputs are seen except with drive powers above 300 mW taken simultaneously with supply voltages below 4 or 5 volts. This condition of simultaneous high drive and low voltage will most likely never be seen in actual applications.

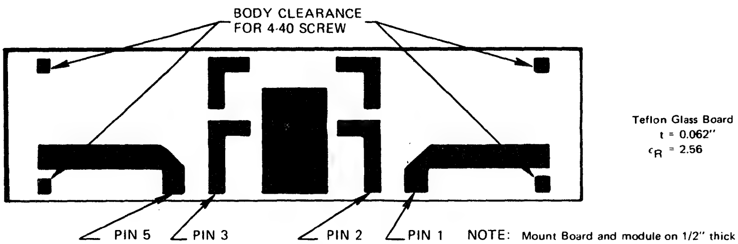
Most problems with module instabilities are a function of poor source impedance or poor decoupling. If a tendency is seen for the module to "snap on" or have hysteresis in the output power versus input power curve, the problem is most likely due to a source VSWR above 2:1 relative to 50 ohms. To check this, put a 3 dB or 6 dB matched pad between the source and the module. The hysteresis or "snap" should disappear if the problem is source impedance. If "jumps" are noticed during varying input power conditions, the problem is most likely low frequency breakup due to insufficient low frequency decoupling – this can be seen on a spectrum analyzer sampling the output power. If a spectrum analyzer is not available, an ac-coupled 10-MHz oscilloscope on the dc feed pins at the module will usually detect low frequency breakup.

When using the module as a drop-in for other modules, it has been found that circuit "tweaks" made to compensate for antenna switching and output filter VSWR to provide optimum performance with a particular type module may degrade the performance of the MHW series modules. The output circuit in this module is a low-pass Chebyshev impedance transforming network. It is carefully designed to provide a 50-ohm source impedance with a VSWR of less than 1.3:1 at 20 watts power output and 12.5 V supply. The power available to the load (forward power as measured by a directional coupler) with this module will not degrade more than 20% from the power set into a 50 ohm load when a load with a VSWR of 2:1 is placed on the output and varied through all phase angles. This characteristic holds true throughout the rated frequency range of the module.

**Load Mismatch**

When performing a load mismatch capability test with any semiconductor device, especially in a new environment where all sources of regeneration are not yet identified, one should monitor the output of the device with a directional sampling scheme and display this output on a spectrum analyzer. It has been found that at least 90 percent of semiconductor failures during load mismatch tests are due to spurious breakup during the test. When the spurious problems are solved, the burnout problems are also solved.

**VHF TEST FIXTURE PC BOARD**




NOTE: Mount Board and module on 1/2" thick aluminum block for heat sinking and electrical ground. Pin 4 is not directly connected to ground in this test fixture. Ground is provided through module heat sink.

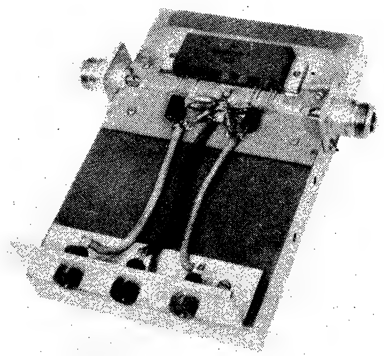
The MHW modules are 100% tested for burnout and spurious breakup two times during the production process. One test is performed after the module is completed and on the heatsink, another is performed after the module is capped and marked. The 20 watt modules are tested at 30 watts output into a load with a return loss of less than 0.7 dB at all phase angles (greater than 25:1 VSWR) and the 13 watt modules are tested at 19 watts into the same load.

In summary, it is recommended that the MHW601/602 series modules be operated under the following conditions:

1. Source and load VSWR $\leqslant$2:1 with respect to 50 ohms.
2. Proper low frequency decoupling.
3. Supply voltage of 12.5 volts applied to both pin 3 and pin 2 with driver power adjusted for desired output power.
4. Sufficient heatsinking so that module flange does not exceed 100$^{\circ}$C (preferably 80$^{\circ}$C).
5. Flange at rf ground potential. The "ground" pin 4 is not sufficient to establish a good rf ground at VHF by itself.

When these rules are followed, the MHW601/602 series modules will provide the performance you expect.

# How To Apply The MHW709/MHW710 UHF Power Modules



**UHF Power Module Test Information (MHW709 and MHW710)**

**TEST CIRCUIT**

Motorola's UHF Power Modules use thin film construction to minimize parasitics, and for manufacturing consistency. They're flange mount for easy, one-sided assembly. They reduce your system inventory, eliminate the need for special production equipment. But even though the MHW709/MHW710 are "complete" UHF power drivers and reduce RF design and production to a new level of ease, there are a few operation and testing considerations to follow for best results.

The modules are conservatively rated. Actual output power capability is 50 to 70% above rated power. However, the equipment designer should not design a product using the module above the rated output power. In some cases, if smaller margins are acceptable and certain other conditions are met, some of the reserve power output can be used. In this case, please contact your Motorola representative for specific recommendations.

When operated within published specifications, the maximum device current density seen in a limit module will be $1.5 \times 10^5$ A/cm$^2$. Maximum die temperature with a 100° C base plate temperature will be 165° C.

Nominal ratings are for a 12.5 Vdc supply ($V_s$ at pin 5) and control ($V_{sc}$ at pin 3) voltage. Specifications such as power gain, efficiency, and input VSWR are measured with the nominal 12.5 Vdc supply and an output power of 13 W (MHW710) and 7.5 W (MHW709).

### Gain Control

The preferred method of operation is to apply 12.5 Vdc to both pin 3 and pin 5 through the recommended decoupling network. (In general, the module output power should be limited to 14 W, MHW710; 8.5 W, MHW709.) The output of the module is then set by adjusting the input drive level. Operation in this manner will result in the best performance with temperature variation.

Pin 5 supplies collector voltage to the input stage in the module. This pin is internally bypassed by a .018 μF chip capacitor effective for frequencies from 5 MHz through the operating frequency. Due to size limitations in the module, additional external low frequency decoupling effective below 5 MHz is required (as is required with discrete UHF transistors). If pin 5 is used to

reduce the module output, two characteristics may cause an application problem.

One is that with the drive power appreciably above that required (+2 dB or so) for 13 watts output, the voltage on the first stage may be as low as four or five volts. This low voltage tends to increase the slump in output power with increasing temperature as opposed to the condition of pin 5 = pin 3 = 12.5 V and drive adjusted for desired power output. Second, if voltage to pin 5 is derived from a series dropping resistor and the value of the resistor is above 10 to 20 ohms, the output power will tend to rise with decreasing drive which could cause problems in an application using an automatic gain or output leveling circuit. If pin 5 is fed from a regulated voltage source, as opposed to a series dropping resistor, this problem does not arise, however, the temperature slump characteristic is still present.

Typically, the MHW710 slump at 80° C from rated output at 25° C with V3 = V5 = 12.5 Vdc is 9 to 12%. With pin 5 voltage set for rated output power and rated drive applied, the typical slump will be 10 to 16% at 80° C. Slump in the MHW709 under the same conditions is typically 5% less than the above figures.

## Decoupling

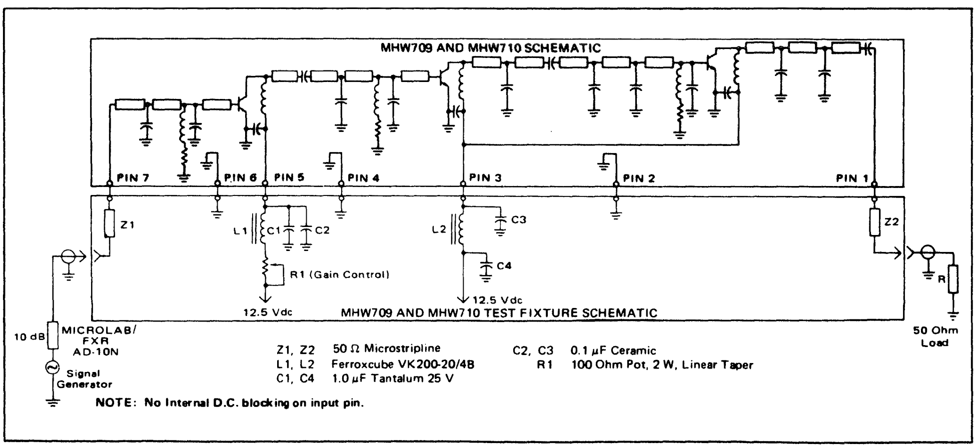
As mentioned, size limitations in the module make it necessary to provide external coupling for frequencies below 5 or 10 MHz. This can take the form of a network as shown on the data sheet. All decoupling capacitors internal to the module are .018 $\mu$F chips. Output and interstage blocking capacitors are 39 pF NPO chips. This chip type has a nominal reactance to 9 ohms in the UHF band and was selected to decrease the module gain at frequencies below the pass band. Also, the base return chokes in all stages were selected to degrade gain slightly at UHF with greater effect at lower frequencies. The use of small coupling and blocking capacitors along with low impedance base returns reduces the loop gain at low frequencies to minimize low frequency problems from the increased device gains below the operating frequency.

The decoupling network shown on the data sheet is used during final test of the module and has been found effective for our test setup. Differences in test circuit layout, ground current paths or other low frequency feedback circuits could require a modified decoupling network. Some applications may benefit from the use of a series R-C damping circuit connected to ground from pins 5 or 3. This can consist of a 5 to 10 ohm carbon resistor in series with a 1 to 10 $\mu$F, 25 volt electrolytic or tantalum capacitor.

## Source and Load Impedances

The modules are designed for proper operation with source and load impedances of 50 ohms resistive. With proper decoupling, they will be stable with 2:1 VSWR source and load impedances, any phase angle and any combination of phase angles at nominal drive and power output. In addition, the rf drive and supply voltage can be varied over wide ranges. Typically, during this test, no spurious outputs are seen except with drive powers above 300 mW taken simultaneously with supply voltages below 4 or 5 volts. This condition of simultaneous

UHF POWER MODULE TEST SETUP



high drive and low voltage will most likely never be seen in actual applications.

Most problems with module instabilities are a function of poor source impedance or poor decoupling. If a tendency is seen for the module to "snap on" or have hysteresis in the output power versus input power curve, the problem is most likely due to a source VSWR above 2:1 relative to 50 ohms. To check this, put a 3 dB or 6 dB matched pad between the source and the module. The hysteresis or "snap" should disappear if the problem is source impedance. If "jumps" are noticed during varying input power conditions, the problem is most likely low frequency breakup due to insufficient low frequency decoupling–this can be seen on a spectrum analyzer sampling the output power. If a spectrum analyzer is not available, an ac-coupled 10 MHz oscilloscope on the dc feed pins at the module will usually detect low frequency breakup.

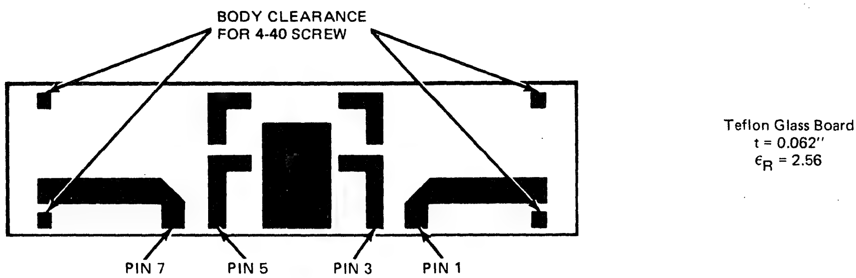
all phase angles. This characteristic holds true throughout the rated frequency range of the module.

**Load Mismatch**

When performing a load mismatch capability test with any semiconductor device, especially in a new environment where all sources of regeneration are not yet identified, one should monitor the output of the device with a directional sampling scheme and display this output on a spectrum analyzer. It has been found that at least 90 percent of semiconductor failures during load mismatch tests are due to spurious breakup during the test. When the spurious problems are solved, the burnout problems are also solved.

The MHW modules are 100% tested for burnout and spurious breakup two times during the production process. One test is performed after the module is com-

**UHF POWER MODULE TEST FIXTURE PRINTED CIRCUIT BOARD**




NOTE:
Mount board and module on 1/2" thick aluminum block for heat sinking and electrical ground. Pins 2, 4 and 6 are not directly connected to ground in this test fixture. Ground is provided through module heat sink.

When using the module as a drop-in for other modules, it has been found that circuit "tweaks" made to compensate for antenna switching and output filter VSWR to provide optimum performance with a particular type module may degrade the performance of the MHW series modules. The output circuit in this module is a low-pass Chebyshev impedance transforming network. It is carefully designed to provide a 50 ohm source impedance with a VSWR of less than 1.3:1 at 13 watts power output and 12.5 V supply. The power available to the load (forward power as measured by a directional coupler) with this module will not degrade more than 20% from the power set into a 50 ohm load when a load with a VSWR of 2:1 is placed on the output and varied through

pleted and on the heatsink, another is performed after the module is capped and marked. The 13 watt modules are tested at 17 to 20 watts output into a load with a return loss of less than 0.7 dB at all phase angles (greater than 25:1 VSWR) and the 7.5 watt modules are tested at 10 to 12 watts into the same load.

In summary, it is recommended that the MHW709/710 series modules be operated under the following conditions:

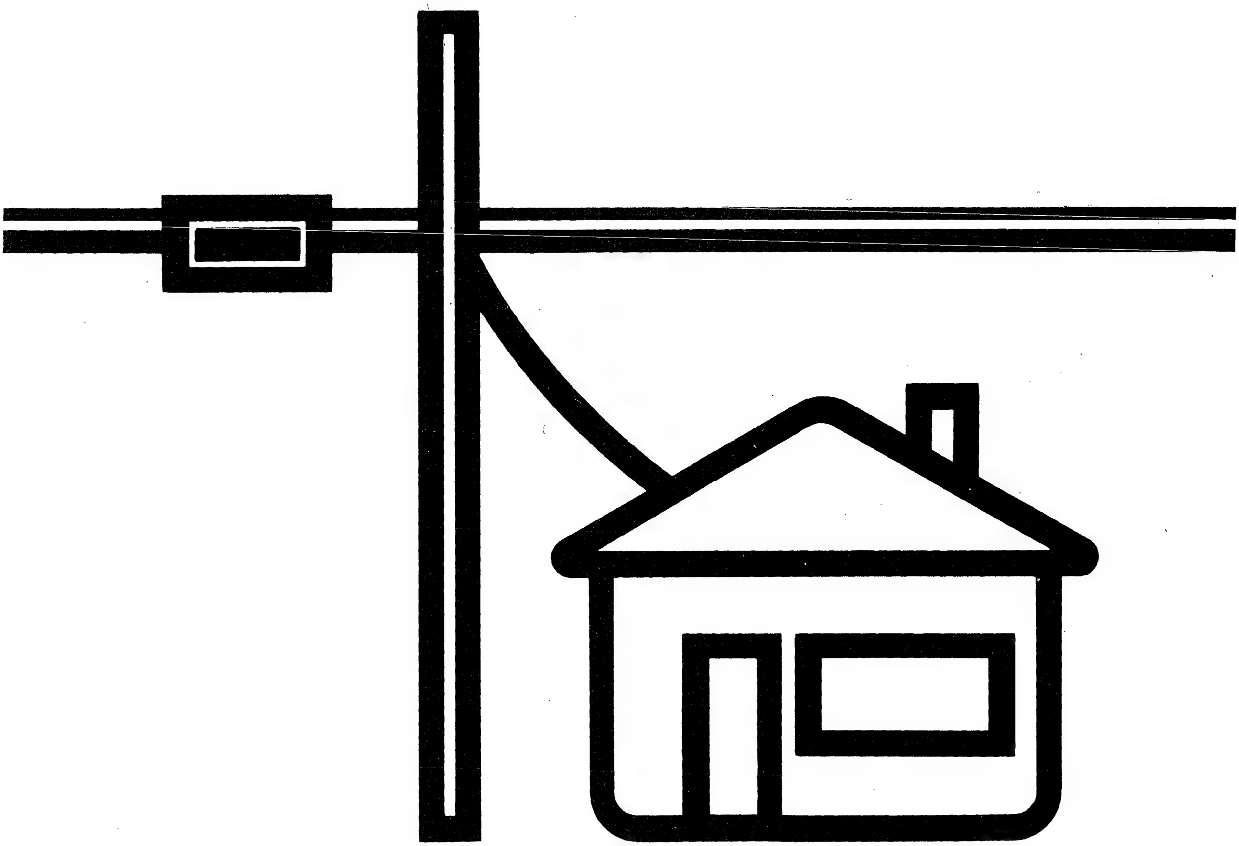
1. Source and load VSWR $\leqslant$2:1 with respect to 50 ohms.
2. Proper low frequency decoupling.

3. Supply voltage of 12.5 volts applied to both pin 5 and pin 3 with driver power adjusted for desired output power.
4. Sufficient heatsinking so that module flange does not exceed 100° C (preferably 80° C).
5. Flange at rf ground potential. The "ground" pins 2, 4, and 6 are not sufficient to establish a good rf ground at UHF by themselves.

When these rules are followed, the MHW709/710 series modules will provide the performance you expect.

# HYBRID LINEAR AMPLIFIER MODULES

# CHAPTER 15



# HYBRID LINEAR AMPLIFIER MODULES

Motorola linear hybrid amplifiers are housed in an industry standard package and specified for use in MATV/CATV and general purpose 50–100 ohm applications. Available gains are from 12.0 to 39.0 dB, over 1.0 watt RF power-handling capability, with bandwidths of 1.0 to 400 MHz, and supply voltages of 13.6 and 24 Vdc.

The following chart summarizes the Motorola RF linear hybrid lineup.

| DEVICE | BANDWIDTH MHz | GAIN dB | Vdc V | Idc mA | APPLICATIONS |
|---|---|---|---|---|---|
| MHW1121 | 40-300 | 12.0 | ±24 | 160 | 1 |
| MHW1122 | 40-300 | 12.0 | ±24 | 200 | 2,3 |
| MHW1171 | 40-300 | 17.0 | ±24 | 160 | 1 |
| MHW1172 | 40-300 | 17.0 | ±24 | 200 | 2,3 |
| MHW1221 | 40-300 | 22.0 | ±24 | 180 | 1 |
| MHW1222 | 40-300 | 22.0 | ±24 | 220 | 2,3 |
| MHW1341 | 40-300 | 34.0 | 24 | 300 | 1,2 |
| MHW1342 | 40-300 | 34.0 | 24 | 300 | 1,2 |
| MHW1391* | 40-300 | 39.0 | 24 | 300 | 1,2,3 |
| MHW1392* | 40-300 | 39.0 | 24 | 300 | 1,2,3 |
| MHW1182 | 5-120 | 18.5 | ±24 | 200 | 1,2,3 |
| MHW590 | 10-400 | 34.0 | 24 | 300 | 3 |
| MHW591 | 1-250 | 36.5 | 13.6 | 300 | 3 |
| MHW592 | 1-250 | 36.0 | 24 | 300 | 3 |
| MHW593 | 10-400 | 35.5 | 13.6 | 300 | 3 |

*To be introduced
1. MATV/CATV input amplifier
2. MATV/CATV output amplifier
3. 50–100 ohm small-signal linear and medium power amplifier

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## General Construction

All Motorola RF linear hybrids use ultra-low distortion, push-pull cascode circuitry to achieve wide bandwidth, extremely flat response and low distortion products.

Units with 22 dB or less of gain consist of a transistor push-pull cascode stage (common-emitter device followed by common base device) for a total of four transistors and two transformers. A bifilar transformer is used at the input and a trifilar at the output.

Units with 34 dB or more of gain use two push-pull cascode stages, giving a total of eight transistors. One transformer at the interstage between the two push-pull gain blocks brings the transformer count to three, one bifilar and two trifilar.

## Processes

The hybrid amplifiers are built using a thin-film circuit process on an alumina substrate. A nichrome metal pattern is evaporated on the alumina ceramic to form resistors and to serve as a ceramic-to-gold interface. A thin pattern of evaporated gold metal followed by a thick plated gold pattern is then deposited on the substrate to form all gold conductive pads and lines. Nichrome resistors are precision trimmed to ±1% in value by a computerized laser-trimming system.

Component attachment to the alumina substrate is performed by a flux-free solder reflow technique using a hydrogen atmosphere as the reducing agent and gold tin solder attachment. Transistor die previously bonded on molybdenum heat spreaders for thermal conductivity, chip capacitors, and feed-through leads are all attached using the high melting point, high tensile strength, gold-tin solder without the corrosive residues of flux being introduced in the operation.

The wirebonding technique used is ultrasonic, using 1.5 mil gold wires to interconnect the all gold metal transistor die and substrate circuitry. The uniformity of all gold transistor die, gold wirebonds, and gold substrate interconnects enhances reliability by eliminating dissimilar metal interfaces.

A hydrogen atmosphere reflow solder technique is used to attach the ceramic substrate to the gold-plated aluminum heat sink. The indalloy solder used melts at a temperature sufficiently low to prevent the gold-tin solder affixing the components from reflowing during heat-sink attach. The extremely flexible indalloy solder greatly enhances

reliability by having a temperature coefficient between that of the aluminum heat sink and the alumina substrate and physically absorbs stresses caused by the difference in temperature coefficient of the two materials during temperature cycling.

A plastic bridge is epoxied to the substrate for protection of components and physical support of the transformers. Transformers which have been previously wound on specially selected temperature-stable ferrite cores are attached to the module assembly.

Completed assemblies are tuned for desired gain response and return loss. For low current applications, a gold wire bond shorting a resistor in the bias chain is removed to reduce current. Plastic caps are epoxied onto the module prior to complete final testing of all dc and RF parameters, including a retest of the gain response and return loss performances.

## Transistor Die

The RF hybrid module is a complex transistor circuit involving a number of components. In the design and manufacturing of Motorola's RF linear hybrids every passive component as well as the transistor die, transformers, substrate, and package are given careful reliability consideration. Since Motorola's unique flux-free component attach technique, the stress-relieving final assembly technique, and the pretinning of all transformers and pads have been previously discussed, it is appropriate now to discuss the most important, yet most reliable, component of the RF hybrid, the transistor die.

The most common cause of failure in RF transistors is electrical overstress. Since the transistors in Motorola RF linear hybrids operate in an environment of optimum bias and careful input and output match, the major causes of electrical overstress are transients on the supply line. The characteristics of an RF transistor which provides resistance to failure from these transients (thickness and resistivity of the collector epitaxial layer) are extremely important factors in determining the RF gain and distortion performance. Thus, resistance to transients can be improved only at the expense of electrical performance. Motorola CATV transistors are designed to provide the best compromise of ruggedness and high electrical performance.

Electromigration is a highly publicized phenomenon which, under certain conditions, can become a failure mode in RF transistors. It is a transport of metal ions which occurs when high current densities are present at high temperatures. For a given set of conditions, light metal ions such as aluminum are more prone to migrate than are heavy metal ions such as gold. The process of electromigration in aluminum-metallized transistors is begun through a reaction at the silicon-aluminum interface with the silicon dissolving into the aluminum. Between the two, barrier metals such as nichrome are effective in preventing this reaction and hence retard the onset of migration. Proper transistor design (eliminating metal paths with high current density), low thermal resistance, and good heat-sinking greatly reduce the other factors which contribute to electromigration. At this writing, Motorola linear hybrids, utilizing aluminum-metallized transistor chips have logged over 650,000 unit-hours of life-testing with no degradations or failures. Since each hybrid module contains either four or eight transistor chips, this achievement represents several million failure-free transistor hours.

The design of some of the newer high-performance linear RF transistors requires extremely narrow metal fingers to make contact to the emitter stripes. In this case, the high current densities which result make mandatory the use of gold metallization. Motorola has several years' experience in gold-metallization systems for high reliability RF power and microwave small-signal transistors and is now pleased to offer a state-of-the-art gold-metallized CATV transistor die. The entire lineup of CATV linear hybrids is now available with this all-gold metallization system as denoted by the MHW1000 series of hybrids.

## Quality Assurance

After each assembly process in the manufacture of Motorola RF linear hybrids is a quality assurance station run independently of production by the Motorola quality assurance department. These test stations perform mechnical push-tests on chip capacitors, pull-tests on die and substrate wire bonds, as well as visual inspection on each completed subassembly. Based on a sample, a lot will be rejected if any rejects are found, and that lot must then be 100% tested. Based on those results, the good units will be allowed to pass or, in the case of additional rejects, the assembly process will be shut down until the problem is identified and resolved.

The completed module is subjected to the most rigorous testing of all, in that all dc and RF parameters guaranteed by specification are tested on each and every hybrid. On CATV hybrids, this generally means 100% testing of dc current, RF gain, input and output return loss, intermodulation distortion, cross-modulation distortion at both ends of the band, composite and three-channel triple beat, and noise figure. These tests are all run at a nominal 100°C case temperature, serving as an effective burn-in as well as performance assurance.

Extensive reliability testing, both mechnical and dc operating life, have been performed on these hybrids with a total of 650,000 hybrid-hours so far accumulated without one failure or degradation. Details of all reliability testing performed are available on request.

**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MHW590

## The RF Line

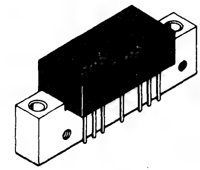
**10–400 MHz**

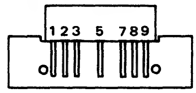
**HIGH GAIN AMPLIFIER**

## LOW DISTORTION WIDEBAND AMPLIFIER MODULE

. . . low-noise, high-gain, ultra-linear, thin-film hybrid. Designed for multi-purpose broadband 50 to 100 ohm system applications requiring superior gain and current stability with temperature.

- Supply Voltage = 24 V Nominal
- Broadband Power Gain —
  $G_p$ = 34 dB (Typ) @ f = 10-400 MHz
- Broadband Noise Figure —
  NF = 3.5 dB (Typ) @ f = 300 MHz
- Ideal for Low Level Wideband Linear Amplifiers and AM Modulators in VHF/UHF Communications Equipment and RF Instrumentation Applications






PIN 1. RF INPUT
5. $V_{DC}$
2,3,7,8. DC AND RF GROUND
9. RF OUTPUT

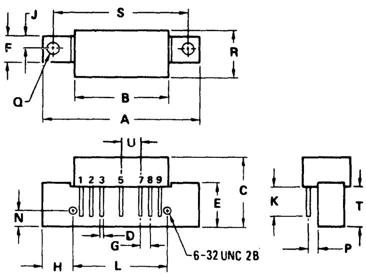
15

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{DC}$ | 28 | Vdc |
| Input Power | $P_{in}$ | 5.0 | dBm |
| Operating Case Temperature Range | $T_C$ | -20 to +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 to +100 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{DC}$ = 24 Vdc, $Z_o$ = 50 Ω, $T_C$ = 25°C. All characteristics guaranteed over bandwidth listed under "Frequency Range", unless specified otherwise.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Frequency Range | BW | 10 | – | 400 | MHz |
| Power Gain | $G_p$ | 31.5 | 34 | 35.5 | dB |
| Gain Flatness | F | – | – | ±1.5 | dB |
| Voltage Standing Wave Ratio, In/Out | VSWR | | | | |
| (f = 10-300 MHz) | | – | 1.5:1 | – | |
| (f = 300-400 MHz) | | – | 2:1 | – | |
| 1 dB Compression | P1 | | | | mW |
| (f = 10 MHz) | | – | 800 | – | |
| (f = 200 MHz) | | 700 | 800 | – | |
| (f = 400 MHz) | | – | 300 | – | |
| Reverse Isolation | $P_{RI}$ | 43 | 50 | – | dB |
| 2nd Harmonic ($P_{out}$ = 10 mW) | $d_{so}$ | – | -66 | – | dB |
| Third Order Intercept | $I_{TO}$ | – | 43 | – | dBm |
| Peak Envelope Power for -32 dB Distortion | PEP | – | 500 | – | mW |
| Noise Figure | NF | | | | dB |
| (f = 60 MHz) | | – | 4.0 | – | |
| (f = 300 MHz) | | – | 3.5 | 5.5 | |
| DC Voltage | $V_{DC}$ | – | 24 | 28 | V |
| DC Current | $I_{DC}$ | – | 300 | 340 | mA |




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

FIGURE 1 — POWER GAIN AND RETURN LOSS versus FREQUENCY

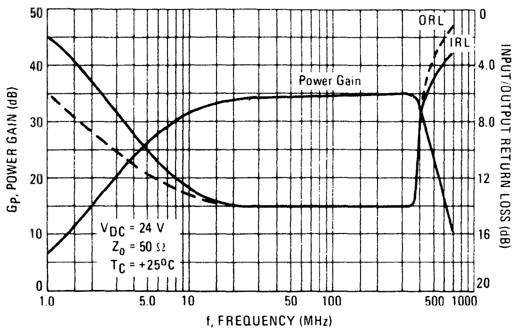



FIGURE 2 — POWER GAIN versus FREQUENCY

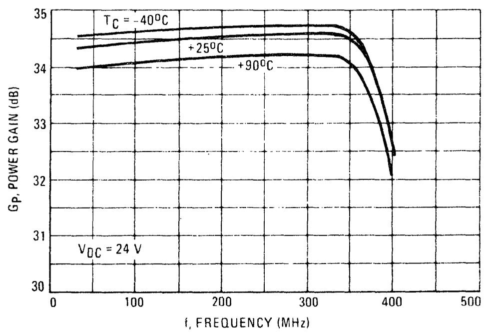



FIGURE 3 — POWER GAIN versus SUPPLY VOLTAGE

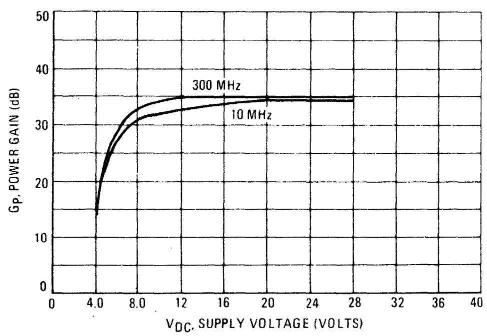



FIGURE 4 — NOISE FIGURE versus SUPPLY VOLTAGE

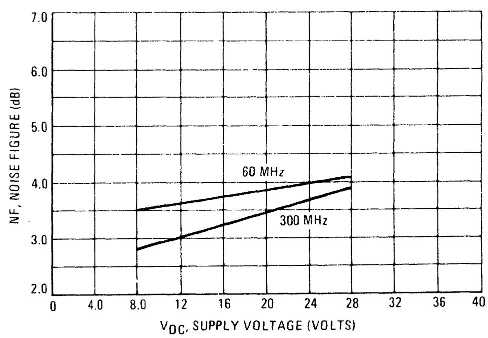



FIGURE 5 — OUTPUT POWER versus INPUT POWER

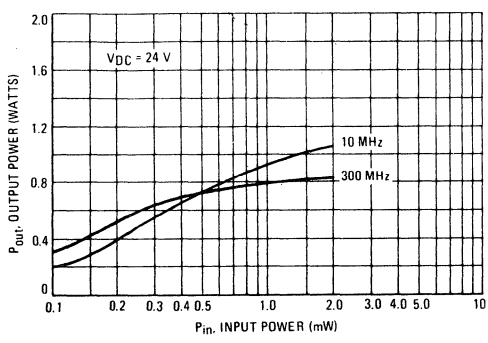



FIGURE 6 — OUTPUT POWER versus INPUT POWER

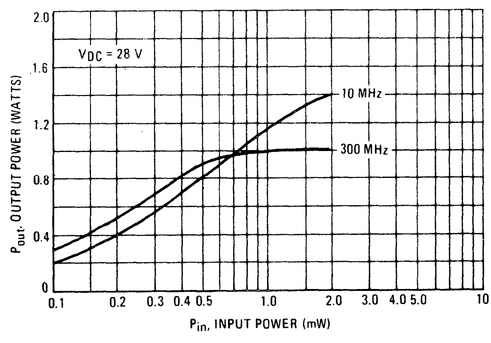


**FIGURE 7 — INTERMODULATION DISTORTION — THIRD ORDER versus OUTPUT POWER**

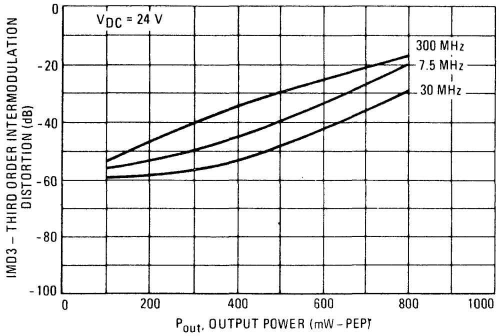



**FIGURE 8 — INTERMODULATION DISTORTION — FIFTH ORDER versus OUTPUT POWER**

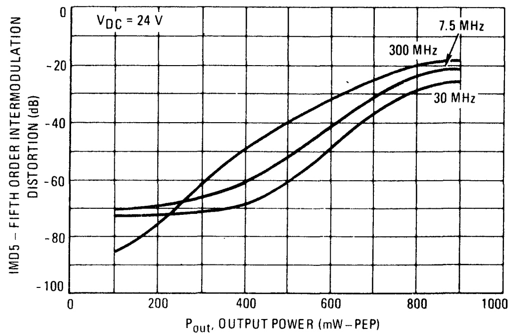



**FIGURE 9 — INTERMODULATION DISTORTION — THIRD ORDER versus OUTPUT POWER**

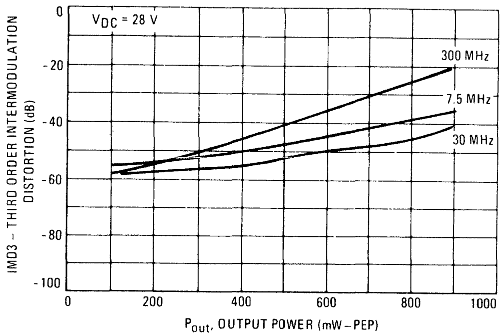



**FIGURE 10 — INTERMODULATION DISTORTION — FIFTH ORDER versus OUTPUT POWER**

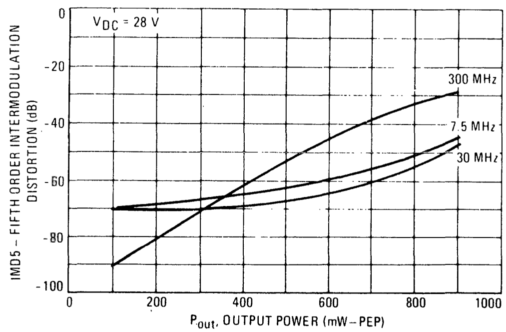
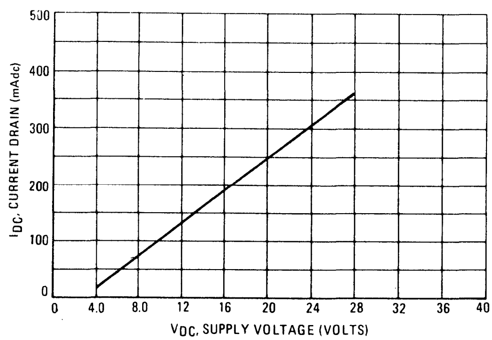



**FIGURE 11 — DC CURRENT DRAIN versus SUPPLY VOLTAGE**



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# MHW591

## The RF Line

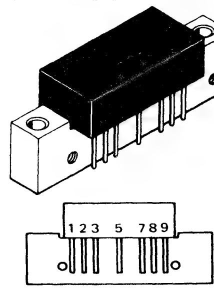
### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

. . . low-noise, high-gain, ultra-linear, thin-film hybrid. Designed for multi-purpose broadband 50 to 100 ohm system applications requiring superior gain and current stability with temperature.

- Supply Voltage = 13.6 V Nominal
- Broadband Power Gain —
  $G_p$ = 36.5 dB (Typ) @ f = 1-250 MHz
- Broadband Noise Figure —
  NF = 3.7 dB (Typ) @ f = 30 MHz
- Ideal for Low Level Wideband Linear Amplifiers and AM Modulators in HF/SSB, VHF Communications Equipment and RF Instrumentation Applications

**1.0–250 MHz**

**HIGH GAIN AMPLIFIER**




PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT

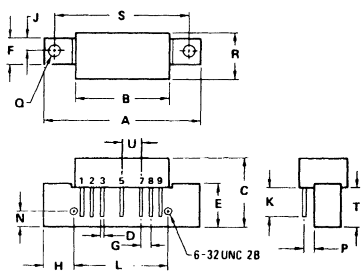
15

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{DC}$ | 16 | Vdc |
| Input Power | $P_{in}$ | 3.0 | dBm |
| Operating Case Temperature Range | $T_C$ | -20 to +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 to +100 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{DC}$ = 13.6 Vdc, $Z_o$ = 50 Ω, $T_C$ = 25°C. All characteristics guaranteed over bandwidth listed under "Frequency Range", unless specified otherwise.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Frequency Range | BW | 1.0 | — | 250 | MHz |
| Power Gain | $G_p$ | 34.5 | 36.5 | 38 | dB |
| Gain Flatness | F | — | — | ±1.5 | dB |
| Voltage Standing Wave Ratio, In/Out | VSWR | | | | |
| (f = 1.0-30 MHz) | | — | 1.5:1 | — | |
| (f = 30-250 MHz) | | — | 2:1 | — | |
| 1 dB Compression | P1 | | | | mW |
| (f = 30 MHz) | | 650 | 800 | — | |
| (f = 100 MHz) | | — | 700 | — | |
| (f = 250 MHz) | | — | 250 | — | |
| Peak Envelope Power | PEP | | | | mW |
| (IMD3 = -30 dB, f = 30 MHz) | | 700 | 850 | — | |
| (IMD3 = -30 dB, f = 100 MHz) | | — | 600 | — | |
| (IMD3 = -30 dB, f = 250 MHz) | | — | 300 | — | |
| Noise Figure | NF | | | | dB |
| (f = 30 MHz) | | — | 3.7 | 5.0 | |
| (f = 100 MHz) | | — | 3.7 | — | |
| (f = 250 MHz) | | — | 4.5 | — | |
| DC Voltage | $V_{DC}$ | — | 13.6 | 16 | V |
| DC Current | $I_{DC}$ | — | 300 | 340 | mA |




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

FIGURE 1 — POWER GAIN versus FREQUENCY

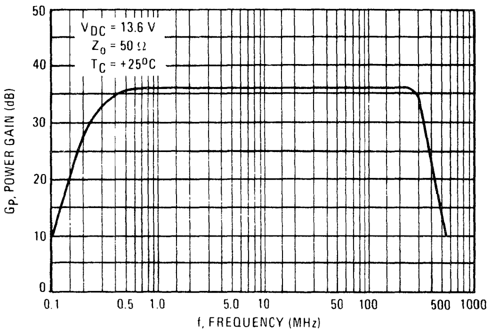



FIGURE 2 — POWER GAIN versus FREQUENCY

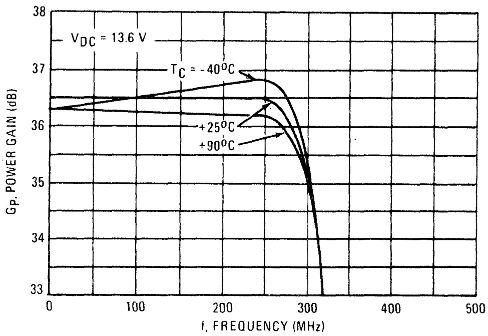



FIGURE 3 — POWER GAIN versus SUPPLY VOLTAGE

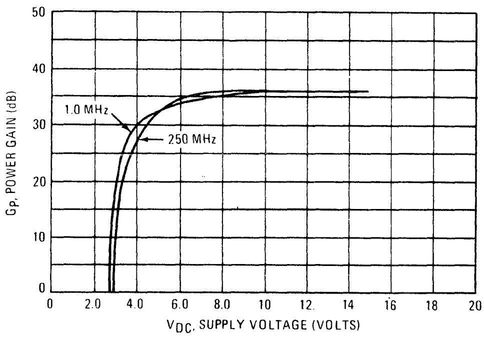



FIGURE 4 — NOISE FIGURE versus SUPPLY VOLTAGE

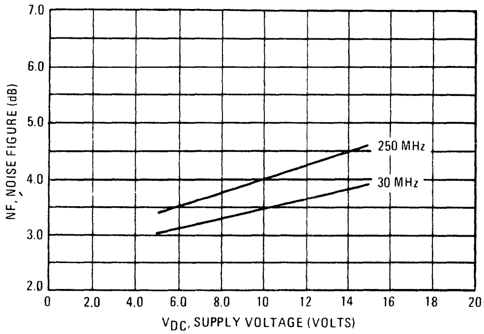



FIGURE 5 — OUTPUT POWER versus INPUT POWER

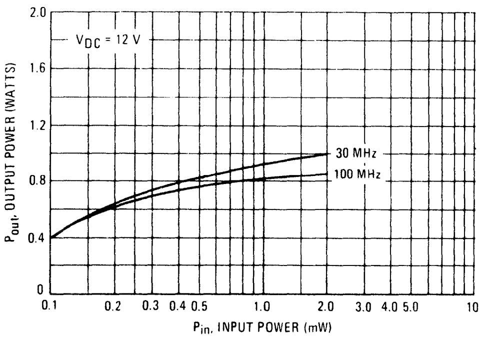



FIGURE 6 — OUTPUT POWER versus INPUT POWER

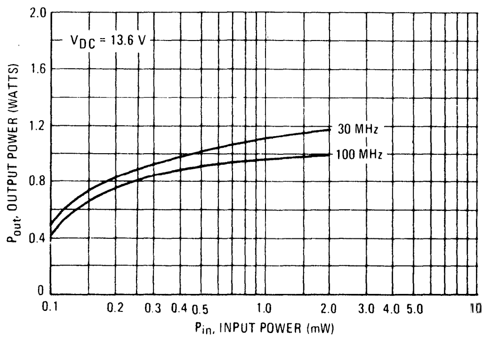


FIGURE 7 — INTERMODULATION DISTORTION versus OUTPUT POWER

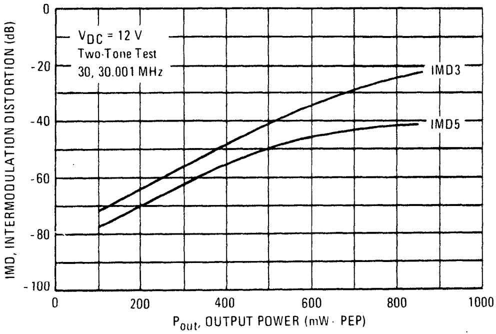



FIGURE 8 — INTERMODULATION DISTORTION versus OUTPUT POWER

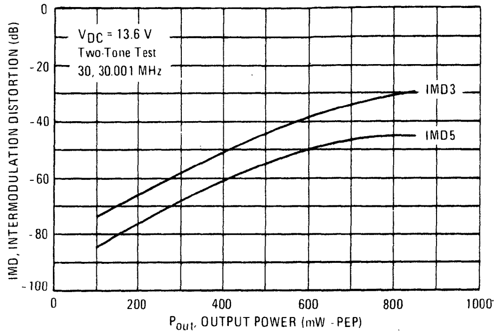
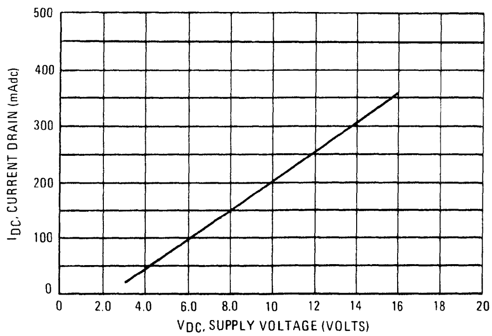



FIGURE 9 — DC CURRENT DRAIN versus SUPPLY VOLTAGE



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BOX 20912 • PHOENIX, ARIZONA 85036

# MHW592

## The RF Line

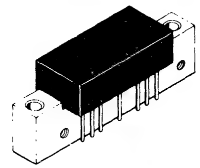
**1.0–250 MHz**

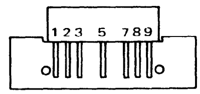
**HIGH GAIN AMPLIFIER**

## LOW DISTORTION WIDEBAND AMPLIFIER MODULE

. . . low-noise, high-gain, ultra-linear, thin-film hybrid. Designed for multi-purpose broadband 50 to 100 ohm system applications requiring superior gain and current stability with temperature.

- Supply Voltage = 24 V Nominal
- Broadband Power Gain — $G_p$ = 35 dB (Typ) @ f = 1-250 MHz
- Broadband Noise Figure — NF = 3.6 dB (Typ) @ f = 30 MHz
- Ideal for Low Level Wideband Linear Amplifiers and AM Modulators in HF/SSB, VHF Communications Equipment and RF Instrumentation Applications





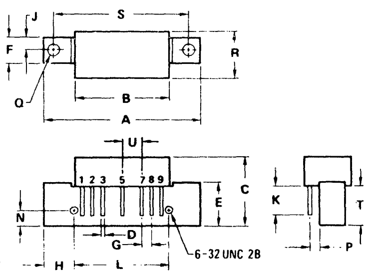

PIN 1. RF INPUT
5. $V_{DC}$
2,3,7,8. DC AND RF GROUND
9. RF OUTPUT

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{DC}$ | 28 | Vdc |
| Input Power | $P_{in}$ | 5.0 | dBm |
| Operating Case Temperature Range | $T_C$ | -20 to +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 to +100 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{DC}$ = 24 Vdc, $Z_o$ = 50 Ω, $T_C$ = 25°C. All characteristics guaranteed over bandwidth listed under "Frequency Range", unless specified otherwise.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Frequency Range | BW | 1.0 | – | 250 | MHz |
| Power Gain | $G_p$ | 33.5 | 35 | 36.5 | dB |
| Gain Flatness | F | – | – | ±1.0 | dB |
| Voltage Standing Wave Ratio, In/Out | VSWR | | | | |
| (f = 1.0-30 MHz) | | – | 1.5:1 | – | |
| (f = 30-250 MHz) | | – | 2:1 | – | |
| 1 dB Compression | P1 | | | | mW |
| (f = 30 MHz) | | 750 | 900 | – | |
| (f = 100 MHz) | | – | 900 | – | |
| (f = 250 MHz) | | – | 750 | – | |
| Peak Envelope Power | PEP | | | | mW |
| (IMD3 = -30 dB, f = 30 MHz) | | 700 | 850 | – | |
| (IMD3 = -30 dB, f = 100 MHz) | | – | 850 | – | |
| (IMD3 = -30 dB, f = 250 MHz) | | – | 600 | – | |
| Noise Figure | NF | | | | dB |
| (f = 30 MHz) | | – | 3.6 | 5.0 | |
| (f = 100 MHz) | | – | 3.7 | – | |
| (f = 250 MHz) | | – | 3.9 | – | |
| DC Voltage | $V_{DC}$ | – | 24 | 28 | V |
| DC Current | $I_{DC}$ | – | 300 | 340 | mA |




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | - | 45.08 | -- | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2 41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

FIGURE 1 – POWER GAIN versus FREQUENCY

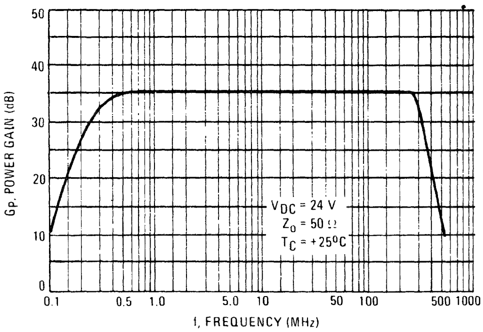



FIGURE 2 – POWER GAIN versus FREQUENCY

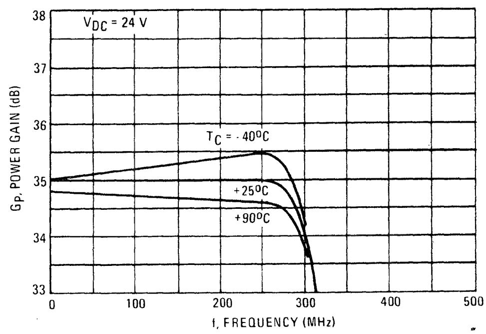



FIGURE 3 – POWER GAIN versus SUPPLY VOLTAGE

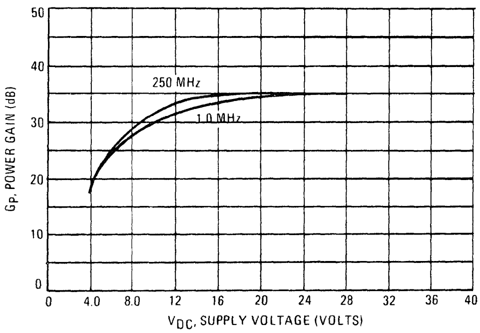



FIGURE 4 – NOISE FIGURE versus SUPPLY VOLTAGE

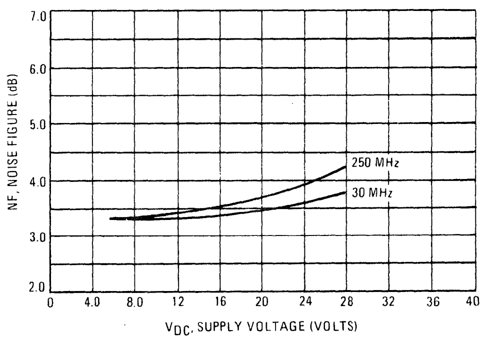



FIGURE 5 – OUTPUT POWER versus INPUT POWER

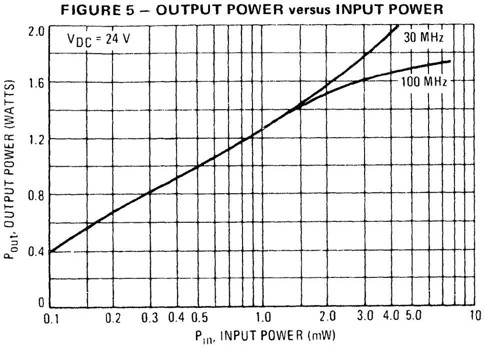



FIGURE 6 – OUTPUT POWER versus INPUT POWER

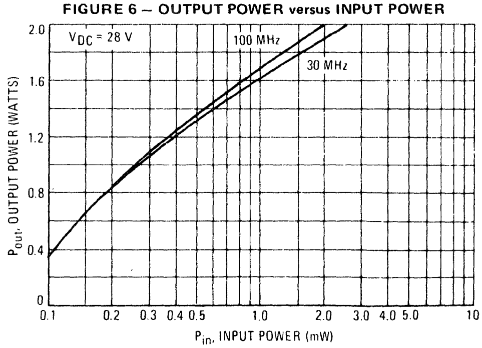


FIGURE 7 – INTERMODULATION DISTORTION versus OUTPUT POWER

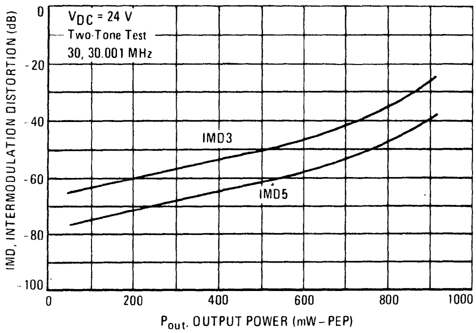



FIGURE 8 – INTERMODULATION DISTORTION versus OUTPUT POWER

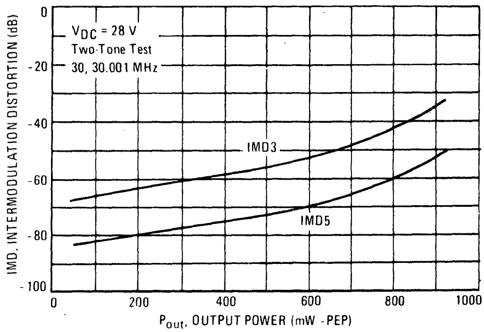
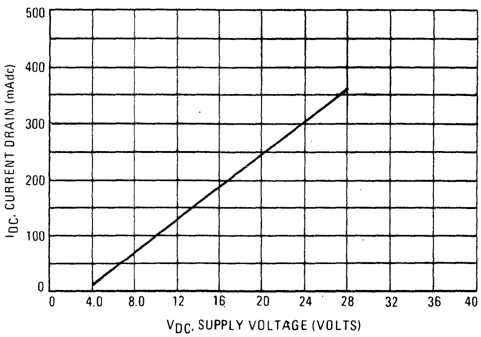



FIGURE 9 – DC CURRENT DRAIN versus SUPPLY VOLTAGE



MOTOROLA
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# MHW593

## The RF Line

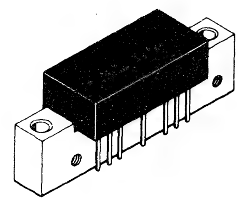
### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

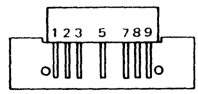
. . . low-noise, high-gain, ultra-linear, thin-film hybrid. Designed for multi-purpose broadband 50 to 100 ohm system applications requiring superior gain and current stability with temperature.

- Supply Voltage = 13.6 V Nominal
- Broadband Power Gain — $G_p$ = 34.5 dB (Typ) @ f = 10-400 MHz
- Broadband Noise Figure — NF = 4.0 dB (Typ) @ f = 300 MHz
- Ideal for Low Level Wideband Linear Amplifiers and AM Modulators in VHF/UHF Communications Equipment and RF Instrumentation Applications

**10–400 MHz**

**HIGH GAIN AMPLIFIER**





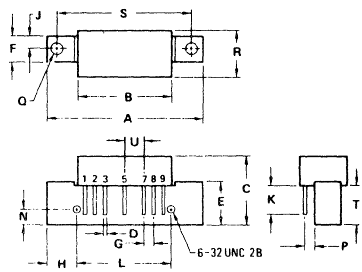

PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{DC}$ | 16 | Vdc |
| Input Power | $P_{in}$ | 3.0 | dBm |
| Operating Case Temperature Range | $T_C$ | -20 to +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 to +100 | °C |

**ELECTRICAL CHARACTERISTICS** ($V_{DC}$ = 13.6 Vdc, $Z_o$ = 50 Ω, $T_C$ = 25°C. All characteristics guaranteed over bandwidth listed under "Frequency Range", unless specified otherwise.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Frequency Range | BW | 10 | – | 400 | MHz |
| Power Gain | $G_p$ | 33 | 34.5 | 36 | dB |
| Gain Flatness | F | – | – | ±1.0 | dB |
| Voltage Standing Wave Ratio, In/Out | VSWR | | | | |
| (f = 10-300 MHz) | | – | 1.5:1 | – | |
| (f = 300-400 MHz) | | – | 2:1 | – | |
| 1 dB Compression | P1 | | | | mW |
| (f = 10 MHz) | | – | 600 | – | |
| (f = 200 MHz) | | 500 | 600 | – | |
| (f = 400 MHz) | | – | 200 | – | |
| Reverse Isolation | $P_{RI}$ | 45 | 50 | – | dB |
| 2nd Harmonic ($P_{out}$ = 10 mW) | $d_{so}$ | – | -55 | – | dB |
| Third Order Intercept | $I_{TO}$ | – | 38 | – | dBm |
| Peak Envelope Power for -32 dB Distortion | PEP | – | 300 | – | mW |
| Noise Figure | NF | | | | dB |
| (f = 60 MHz) | | – | 3.7 | – | |
| (f = 300 MHz) | | – | 4.0 | 5.5 | |
| DC Voltage | $V_{DC}$ | – | 13.6 | 16 | V |
| DC Current | $I_{DC}$ | – | 300 | 340 | mA |




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

FIGURE 1 — POWER GAIN AND RETURN LOSS versus FREQUENCY

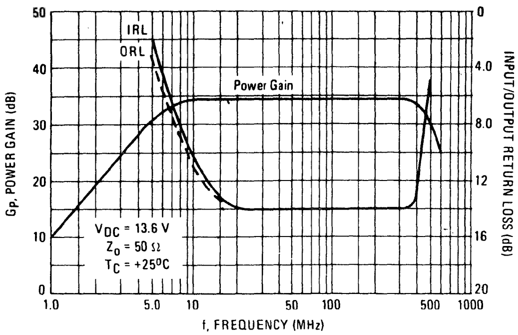



FIGURE 2 — POWER GAIN versus FREQUENCY

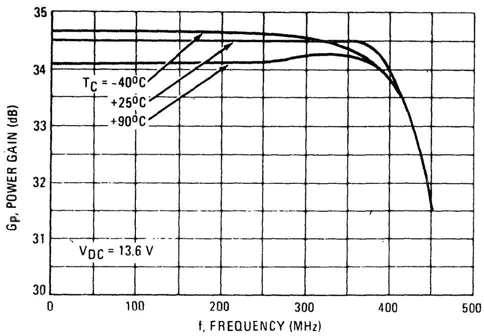



FIGURE 3 — POWER GAIN versus SUPPLY VOLTAGE

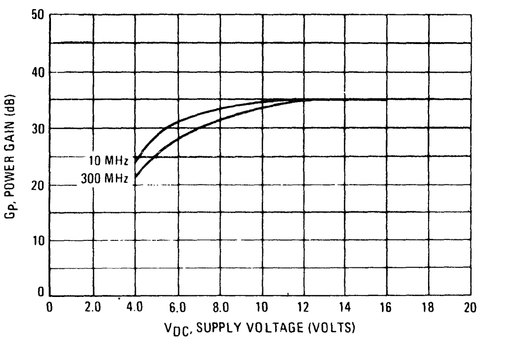



FIGURE 4 — NOISE FIGURE versus SUPPLY VOLTAGE

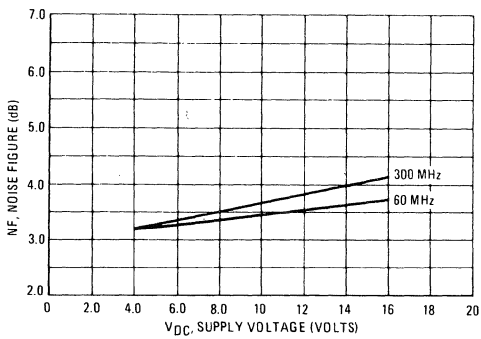



FIGURE 5 — OUTPUT POWER versus INPUT POWER

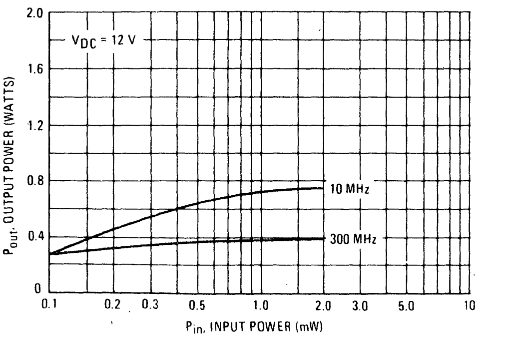



FIGURE 6 — OUTPUT POWER versus INPUT POWER

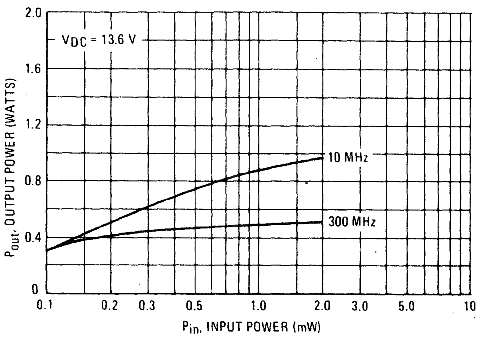


FIGURE 7 — INTERMODULATION DISTORTION — THIRD ORDER versus OUTPUT POWER

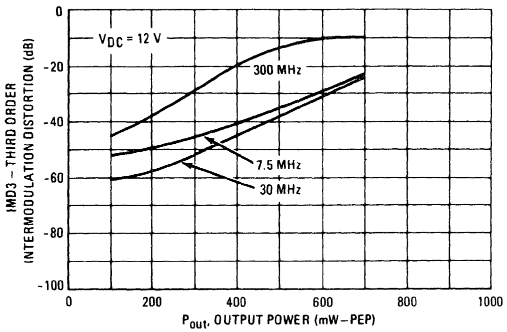



FIGURE 8 — INTERMODULATION DISTORTION — FIFTH ORDER versus OUTPUT POWER

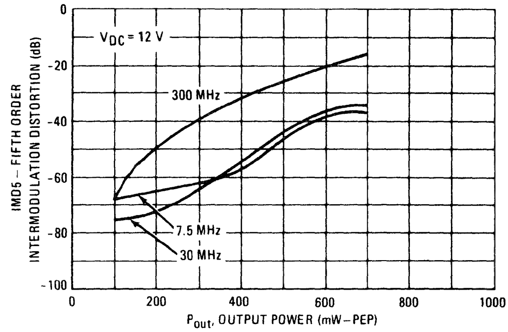



FIGURE 9 — INTERMODULATION DISTORTION — THIRD ORDER versus OUTPUT POWER

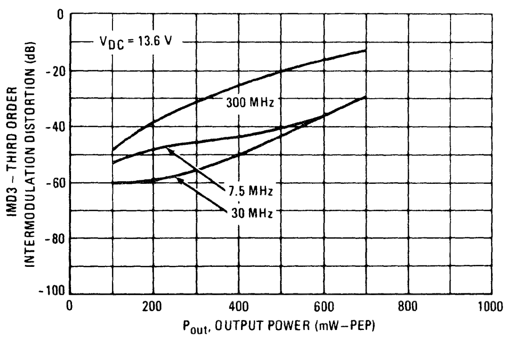



FIGURE 10 — INTERMODULATION DISTORTION — FIFTH ORDER versus OUTPUT POWER

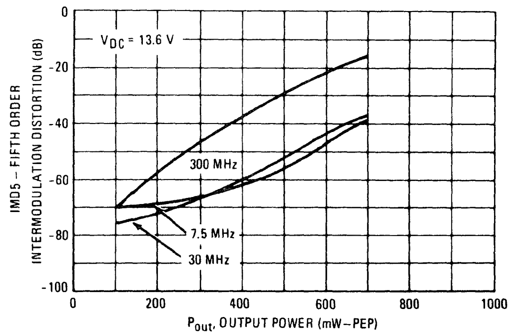
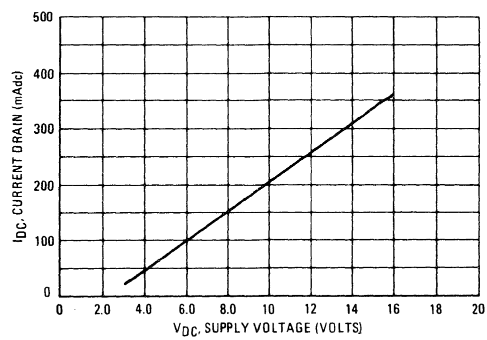



FIGURE 11 — DC CURRENT DRAIN versus SUPPLY VOLTAGE



**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MHW1121 MHW1122

## Product Preview

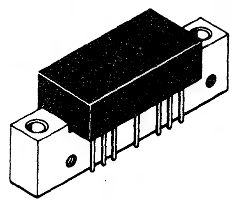
## The RF Line

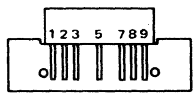
**12 dB GAIN
CATV INPUT/OUTPUT
TRUNK AMPLIFIERS**

### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

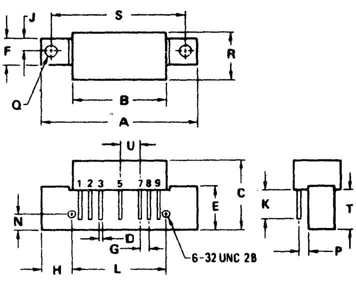
. . . designed specifically for broadband applications requiring low distortion characterisitcs. Specified for use as CATV trunk-line amplifier. Features all-gold metallization system.

- Broadband Power Gain — @ f = 40-300 MHz
  $G_p$ = 12.0 dB (Typ)
- Broadband Noise Figure — @ f = 300 MHz
  NF = 6.0 dB (Typ) MHW1121
  NF = 6.5 dB (Typ) MHW1122
- Superior Gain, Return Loss and DC Current Stability With Temperature
- All-Gold Metallization






PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 24 Vdc, $T_A$ = +25°C unless otherwise noted)

| Characteristics | | Symbol | MHW1121/MHW1122 Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Frequency Range | | BW | 40 | – | 300 | MHz |
| Power Gain – 50 MHz | | $G_p$ | 11.6 | 12.0 | 12.4 | dB |
| Slope | | S | – | +0.4 | +1.0 | dB |
| Gain Flatness | | – | – | ±0.1 | ±0.2 | dB |
| Return Loss – Input/Output ($Z_o$ = 75 Ohms) | | IRL/ORL | 18 | – | – | dB |
| Second Order Intermodulation Distortion ($P_{out}$ = +50 dBmV, Ch 2, 13, R) | | IMD | | | | dB |
| MHW1121 | | | – | -74 | -68 | |
| MHW1122 | | | – | -76 | -70 | |
| Cross Modulation Distortion ($P_{out}$ = +50 dBmV) | | | | | | dB |
| MHW1121 | 12 Channel FLAT | $XMD_{12}$ | – | -65 | – | |
| | 21 Channel FLAT | $XMD_{21}$ | – | -61 | – | |
| | 30 Channel FLAT | $XMD_{30}$ | – | -58 | – | |
| | 35 Channel FLAT | $XMD_{35}$ | – | -56 | -51 | |
| MHW1122 | 12 Channel FLAT | $XMD_{12}$ | – | -69 | – | |
| | 21 Channel FLAT | $XMD_{21}$ | – | -65 | – | |
| | 30 Channel FLAT | $XMD_{30}$ | – | -62 | – | |
| | 35 Channel FLAT | $XMD_{35}$ | – | -60 | -56 | |
| Signal-to-Triple-Beat Noise ($P_{out}$ = +50 dBmV) | | | | | | dB |
| MHW1121 | 12 Channel FLAT | $TB_{12}$ | – | -71 | – | |
| | 21 Channel FLAT | $TB_{21}$ | – | -63 | – | |
| | 30 Channel FLAT | $TB_{30}$ | – | -57 | – | |
| | 35 Channel FLAT | $TB_{35}$ | – | -54 | -51 | |
| MHW1122 | 12 Channel FLAT | $TB_{12}$ | – | -75 | – | |
| | 21 Channel FLAT | $TB_{12}$ | – | -67 | – | |
| | 30 Channel FLAT | $TB_{30}$ | – | -61 | – | |
| | 35 Channel FLAT | $TB_{35}$ | – | -58 | -56 | |
| Noise Figure (f = 300 MHz) | | NF | | | | dB |
| MHW1121 | | | – | 6.0 | 7.0 | |
| MHW1122 | | | – | 6.5 | 8.0 | |
| DC Current ($V_{DC}$ = 24 ±0.5 Vdc, $T_C$ = 30°C) | | $I_{DC}$ | | | | mA |
| MHW1121 | | | – | 160 | 190 | |
| MHW1122 | | | – | 200 | 230 | |
| Operating Case Temperature Range | | $T_C$ | -20 | – | +90 | °C |
| Storage Temperature Range | | $T_{stg}$ | -40 | – | +100 | °C |

**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MHW1171 MHW1172 MHW1221 MHW1222

## Product Preview

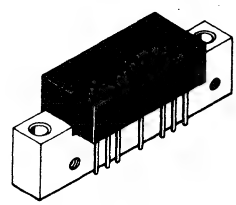
## The RF Line

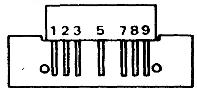
### CATV INPUT/OUTPUT TRUNK AMPLIFIERS

### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

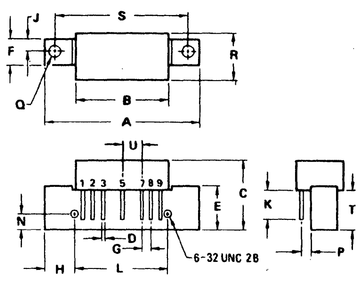
. . . designed specifically for broadband applications requiring low distortion characteristics. Specified for use as CATV trunk-line amplifier. Features all gold metallization system.

- Broadband Power Gain — @ f = 40-300 MHz
  $G_p$ = 17.0 dB (Typ) MHW 1171 MHW1172
  22.0 dB (Typ) MHW 1221 MHW1222
- Broadband Noise Figure — @ f = 300 MHz
  NF = 6.0 db (Typ) MHW1171
  6.5 dB (Typ) MHW1172
  5.0 dB (Typ) MHW1221
  6.0 dB (Typ) MHW1222
- Superior Gain, Return Loss and DC Current Stability with Temperature
- All Gold Metallization






PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 24 Vdc, $T_A$ = +25°C unless otherwise noted.)

| Characteristic | Symbol | MHW1171-MHW1172 Min | Typ | Max | MHW1221-MHW1222 Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Frequency Range | BW | 40 | – | 300 | 40 | – | 300 | MHz |
| Power Gain — 50 MHz | $G_p$ | 16.6 | 17.0 | 17.4 | 21.4 | 22.0 | 22.6 | dB |
| Slope | S | – | +0.4 | +1.0 | – | +0.4 | +1.0 | dB |
| Gain Flatness | – | – | ±0.1 | ±0.2 | – | ±0.1 | ±0.2 | dB |
| Return Loss — Input/Output ($Z_o$ = 75 Ohms) | IRL/ORL | 18 | – | – | 18 | – | – | dB |
| Second Order Intermodulation Distortion ($P_{out}$ = +50 dBmV, Ch 2, 13, R) | IMD | | | | | | | dB |
| MHW1171 MHW1221 | | – | -74 | -68 | – | -72 | -64 | |
| MHW1172 MHW1222 | | – | -76 | -70 | – | -74 | -66 | |
| Cross Modulation Distortion ($P_{out}$ = +50 dBmV) | | | | | | | | dB |
| MHW1171 MHW1221 12 Channel FLAT | $XMD_{12}$ | – | -65 | – | – | -64 | – | |
| 21 Channel FLAT | $XMD_{21}$ | – | -61 | – | – | -60 | – | |
| 30 Channel FLAT | $XMD_{30}$ | – | -58 | – | – | -57 | – | |
| 35 Channel FLAT | $XMD_{35}$ | – | -56 | -51 | – | -55 | -51 | |
| MHW1172 MHW1222 12 Channel FLAT | $XMD_{12}$ | – | -69 | – | – | -68 | – | |
| 21 Channel FLAT | $XMD_{21}$ | – | -65 | – | – | -64 | – | |
| 30 Channel FLAT | $XMD_{30}$ | – | -62 | – | – | -61 | – | |
| 35 Channel FLAT | $XMD_{35}$ | – | -60 | -56 | – | -59 | -56 | |
| Signal-to-Triple Beat Noise ($P_{out}$ = +50 dBmV) | | | | | | | | dB |
| MHW1171 MHW1221 12 Channel FLAT | $TB_{12}$ | – | -71 | – | – | -72 | – | |
| 21 Channel FLAT | $TB_{21}$ | – | -63 | – | – | -64 | – | |
| 30 Channel FLAT | $TB_{30}$ | – | -57 | – | – | -58 | – | |
| 35 Channel FLAT | $TB_{35}$ | – | -54 | -51 | – | -55 | -51 | |
| MHW1172 MHW1222 12 Channel FLAT | $TB_{12}$ | – | -75 | – | – | -74 | – | |
| 21 Channel FLAT | $TB_{21}$ | – | -67 | – | – | -66 | – | |
| 30 Channel FLAT | $TB_{30}$ | – | -61 | – | – | -60 | – | |
| 35 Channel FLAT | $TB_{35}$ | – | -58 | -56 | – | -57 | -55 | |
| Noise Figure (f = 300 MHz) | NF | | | | | | | dB |
| MHW1171 MHW1221 | | – | 6.0 | 7.0 | – | 5.0 | 6.0 | |
| MHW1172 MHW1222 | | – | 6.5 | 8.0 | – | 6.0 | 7.0 | |
| DC Current ($V_{DC}$ = 24 ±0.5 Vdc, $T_C$ = 30°C | $I_{DC}$ | | | | | | | mA |
| MHW1171 MHW1221 | | – | 160 | 190 | – | 180 | 220 | |
| MHW1172 MHW1222 | | – | 200 | 230 | – | 220 | 260 | |
| Operating Case Temperature Range | $T_C$ | -20 | – | +90 | -20 | – | +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 | – | +100 | -40 | – | +100 | °C |

**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MHW1182

## Product Preview

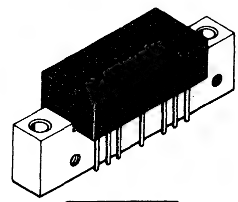
## The RF Line

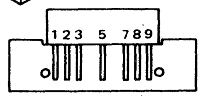
CATV REVERSE AMPLIFIER

### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

. . . designed specifically for broadband applications requiring low distortion characteristics. Specified for use as CATV reverse amplifier. Features all gold metallization system.

- Broadband Power Gain — $G_p$ = 18.5 dB (Typ) @ f = 5–120 MHz
- Broadband Noise Figure — NF = 5.0 dB (Typ) @ f = 100 MHz
- Superior Gain, Return Loss and DC Current Stability with Temperature
- All Gold Metallization

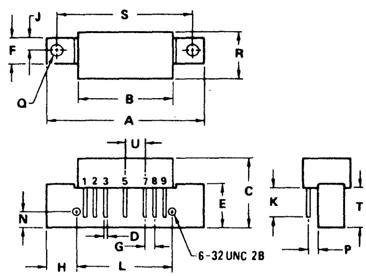





PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 24 Vdc, $T_A$ = +25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Frequency Range | BW | 5.0 | — | 120 | MHz |
| Power Gain — 50 MHz | $G_p$ | 18.0 | 18.5 | 19.0 | dB |
| Gain Flatness | — | — | — | ±0.25 | dB |
| Return Loss — Input/Output ($Z_o$ = 75 Ohms) | IRL/ORL | 18 | — | — | dB |
| Second Order Intermodulation Distortion ($P_{out}$ = +50 dBmV) | IMD | — | -76 | -72 | dB |
| Cross Modulation Distortion ($P_{out}$ = +54 dBmV) 12 Channel FLAT | $XMD_{12}$ | — | -62 | -57 | dB |
| Triple Beat Distortion ($P_{out}$ = +50 dBmV) | | | -86 | -80 | dB |
| Noise Figure (f = 100 MHz) | NF | — | 5.0 | 7.0 | dB |
| DC Current ($V_{DC}$ = 24 ±0.5 Vdc, $T_C$ = 30°C) | $I_{DC}$ | — | 200 | 230 | mA |
| Operating Case Temperature Range | $T_C$ | -20 | — | +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 | — | +100 | °C |




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

CASE 714-01

This is advance information and specifications are subject to change without notice.

MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MHW1341
# MHW1342

## Product Preview

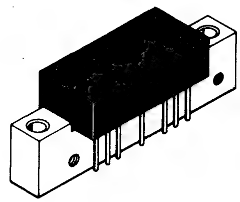
## The RF Line

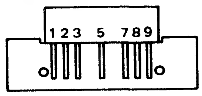
### CATV LINE EXTENDER AMPLIFIERS

### LOW DISTORTION WIDEBAND AMPLIFIER MODULE

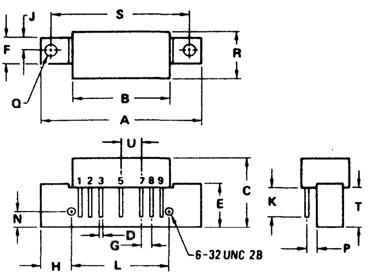
. . . designed specifically for broadband applications requiring low distortion characteristics. Specified for use in CATV distribution equipment. Features all gold metallization system.

- Broadband Power Gain — $G_p$ = 34 dB (Typ) @ f = 40-300 MHz
- Broadband Noise Figure — NF = 5.0 dB (Typ) @ f = 300 MHz
- Superior Gain, Return Loss and DC Current Stability with Temperature
- All Gold Metallization






PIN 1. RF INPUT
2,3,7,8. DC AND RF GROUND
5. $V_{DC}$
9. RF OUTPUT




NOTE:
1. MOUNTING HOLES WITHIN 0.25 mm (0.010) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 45.08 | – | 1.775 |
| B | 26.42 | 26.92 | 1.040 | 1.060 |
| C | 20.57 | 21.34 | 0.810 | 0.840 |
| D | 0.46 | 0.56 | 0.018 | 0.022 |
| E | 11.81 | 12.95 | 0.465 | 0.510 |
| F | 7.87 | 8.13 | 0.310 | 0.320 |
| G | 2.41 | 2.67 | 0.095 | 0.105 |
| H | 9.65 | 9.78 | 0.380 | 0.385 |
| J | 3.96 BSC | | 0.156 BSC | |
| K | 9.65 | 10.41 | 0.380 | 0.410 |
| L | 25.40 BSC | | 1.000 BSC | |
| N | 4.06 | 4.32 | 0.160 | 0.170 |
| P | 2.16 | 2.92 | 0.085 | 0.115 |
| Q | 3.81 | 4.06 | 0.150 | 0.160 |
| R | – | 15.11 | – | 0.595 |
| S | 38.10 BSC | | 1.500 BSC | |
| T | 11.05 | 11.43 | 0.435 | 0.450 |
| U | 4.95 | 5.21 | 0.195 | 0.205 |

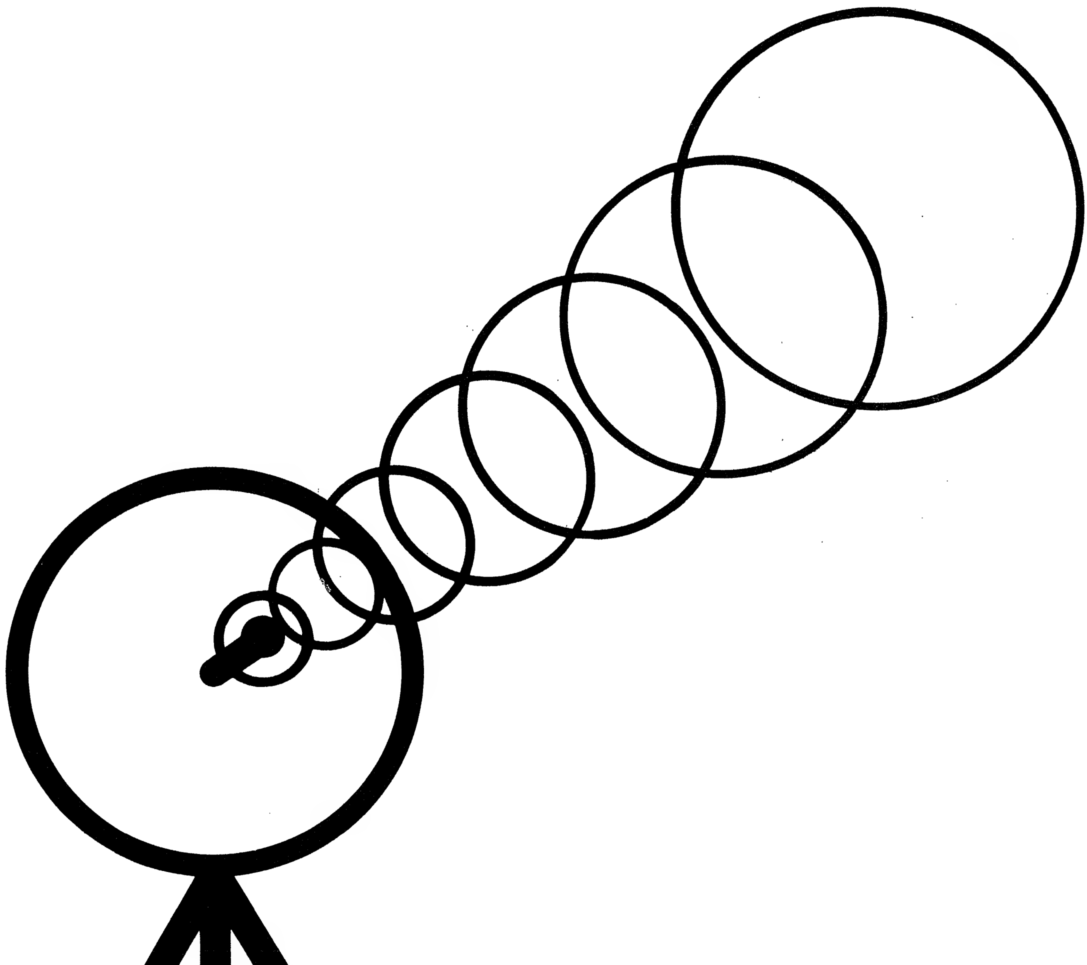
CASE 714-01

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = 24 Vdc, $T_A$ = +25°C unless otherwise noted.)

| Characteristic | Symbol | MHW1341 Min | MHW1341 Typ | MHW1341 Max | MHW1342 Min | MHW1342 Typ | MHW1342 Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Frequency Range | BW | 40 | – | 300 | 40 | – | 300 | MHz |
| Power Gain – 50 MHz | $G_p$ | 33 | 34 | 35 | 33 | 34 | 35 | dB |
| Slope | S | – | +0.6 | +1.5 | – | +0.6 | +1.5 | dB |
| Gain Flatness | – | – | ±0.2 | ±0.5 | – | ±0.2 | ±0.5 | dB |
| Return Loss – Input/Output ($Z_o$ = 75 Ohms) | IRL/ORL | 18 | – | – | 18 | – | – | dB |
| Second Order Intermodulation Distortion ($P_{out}$ = +48 dBmV, Ch 2, 13, R) | IMD | – | -76 | -68 | – | -78 | -70 | dB |
| Cross Modulation Distortion ($P_{out}$ = +48 dBmV) | | | | | | | | dB |
| 12 Channel FLAT | $XMD_{12}$ | – | -69 | – | – | -71 | – | |
| 21 Channel FLAT | $XMD_{21}$ | – | -65 | – | – | -67 | – | |
| 30 Channel FLAT | $XMD_{30}$ | – | -62 | – | – | -64 | – | |
| 35 Channel FLAT | $XMD_{35}$ | – | -60 | -55 | – | -62 | -57 | |
| Signal-to-Triple Beat Noise ($P_{out}$ = +48 dBmV) | | | | | | | | dB |
| 12 Channel FLAT | $TB_{12}$ | – | -75 | – | – | -77 | – | |
| 21 Channel FLAT | $TB_{21}$ | – | -67 | – | – | -69 | – | |
| 30 Channel FLAT | $TB_{30}$ | – | -61 | – | – | -63 | – | |
| 35 Channel FLAT | $TB_{35}$ | – | -58 | -55 | – | -60 | -57 | |
| Noise Figure (f = 300 MHz) | NF | – | 5.0 | 7.0 | – | 5.0 | 7.0 | dB |
| DC Current ($V_{DC}$ = 24 ±0.5 Vdc, $T_C$ = 30°C) | $I_{DC}$ | – | 300 | 330 | – | 300 | 330 | mA |
| Operating Case Temperature Range | $T_C$ | -20 | – | +90 | -20 | – | +90 | °C |
| Storage Temperature Range | $T_{stg}$ | -40 | – | +100 | -40 | – | +100 | °C |

# SMALL-SIGNAL, LOW-POWER CHAPTER 16



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N2857
# 2N3839

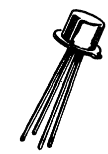
## The RF Line

NPN SILICON
RF SMALL-SIGNAL
TRANSISTORS

### NPN SILICON RF SMALL-SIGNAL TRANSISTORS

. . . designed primarily for use in high-gain, low-noise amplifier, oscillator, and mixer applications. Can also be used in UHF converter applications.

- High Current-Gain—Bandwidth Product —
  $f_T$ = 1.6 GHz (Typ) @ $I_C$ = 8.0 mAdc
- Low Noise Figure —
  NF = 3.9 dB (Max) @ f = 450 MHz — 2N3839
- Low Collector-Base Time Constant —
  $r_b'C_c$ = 15 ps (Max) @ $I_E$ = 2.0 mAdc
- Characterized with Scattering Parameters
- Ideal for Micro-Power Applications



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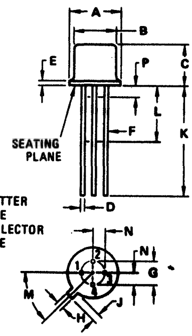
### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 30 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 2.5 | Vdc |
| Collector Current — Continuous | $I_C$ | 40 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 300<br>1.72 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.




STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

CASE 20-03
TO-72

*ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage** ($I_C$ = 3.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 1.0 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 30 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 10 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 2.5 | – | – | Vdc |
| Collector Cutoff Current | $I_{CBO}$ | | | | μAdc |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0) Both Types | | – | – | 0.01 | |
| ($V_{CB}$ = 15 Vdc, $I_E$ = 0, $T_A$ = 150°C) 2N3839 | | – | – | 1.0 | |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 3.0 mAdc, $V_{CE}$ = 1.0 Vdc) | $h_{FE}$ | 30 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product ① ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 100 MHz) 2N2857 | $f_T$ | 1000 | – | 1900 | MHz |
| 2N3839 | | 1000 | – | 2000 | |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{cb}$ | – | 0.7 | 1.0 | pF |
| Small-Signal Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 1.0 kHz) | $h_{fe}$ | 50 | – | 220 | – |
| Collector-Base Time Constant ($I_E$ = 2.0 mAdc, $V_{CB}$ = 6.0 Vdc, f = 31.9 MHz) 2N2857 | $r_b'C_c$ | 4.0 | – | 15 | ps |
| 2N3839 | | 1.0 | – | 15 | |
| Noise Figure (Figure 1) | NF | | | | dB |
| ($I_E$ = 0.1 mAdc, $V_{CE}$ = 1.0 Vdc, $R_S$ = 50 ohms, f = 450 MHz) ② Both Types | | – | 5.8 | – | |
| ($I_C$ = 1.5 mAdc, $V_{CE}$ = 6.0 Vdc, $R_S$ = 50 ohms, f = 450 MHz) 2N2857 | | – | 4.1 | 4.5 | |
| 2N3839 | | – | – | 3.9 | |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) | $G_{pe}$ | | | | dB |
| ($I_E$ = 0.1 mAdc, $V_{CE}$ = 1.0 Vdc, f = 450 MHz) ② | | – | 11 | – | |
| ($I_C$ = 1.5 mAdc, $V_{CE}$ = 6.0 Vdc, f = 450 MHz) | | 12.5 | – | 19 | |
| Power Output (Figure 2) ($I_E$ = 12 mAdc, $V_{CB}$ = 10 Vdc, f = 500 MHz) | $P_{out}$ | 30 | – | – | mW |

*Indicates JEDEC Registered Data.
**Motorola guarantees this data in addition to JEDEC Registered Data.
① $f_T$ is defined as the frequency at which $|h_{fe}|$ extrapolates to unity.
② Micro-Power Specifications.

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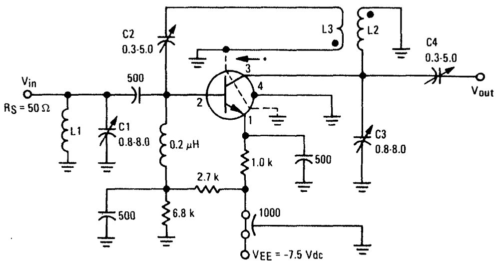
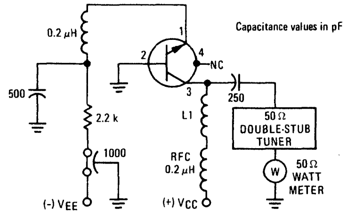
**FIGURE 1 – TEST CIRCUIT FOR NOISE FIGURE AND POWER GAIN**




Capacitance values in pF

**FIGURE 2 – TEST CIRCUIT FOR OSCILLATOR POWER OUTPUT**




L1 – 3 turns #16 AWG wire, 3/8″ O.D. 1-1/4″ long.

L1, L2 – Silver-plated brass rod, 1-1/2″ long and 1/4″ dia. Install at least 1/2″ from nearest vertical chassis surface.
L3 – 1/2 turn #16 AWG wire, located 1/4″ from and parallel to L2.
* – External interlead shield to isolate collector lead from emitter and base leads.

Neutralization Procedure:

(A) Connect 450-MHz signal generator (with $R_S$ = 50 ohms) to input terminals of amplifier.
(B) Connect 50-ohm RF voltmeter across output terminals of amplifier.
(C) Apply $V_{EE}$, and with signal generator adjusted for 5 mV output from amplifier, tune C1, C3, and C4 for maximum output.
(D) Interchange connections to signal generator and RF voltmeter.
(E) With sufficient signal applied to output terminals of amplifier, adjust C2 for minimum indication at input.
(F) Repeat steps (A), (B), and (C) to determine if retuning is necessary.

**FIGURE 3 – NOISE FIGURE versus FREQUENCY**

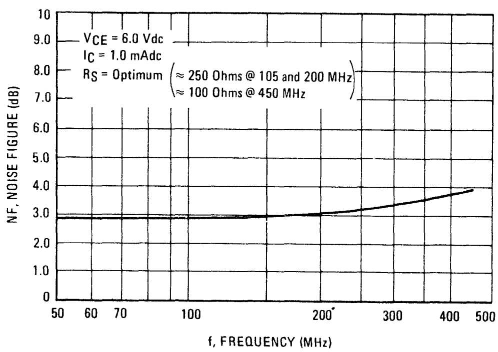



**FIGURE 4 – NOISE FIGURE versus SOURCE RESISTANCE AND COLLECTOR CURRENT**

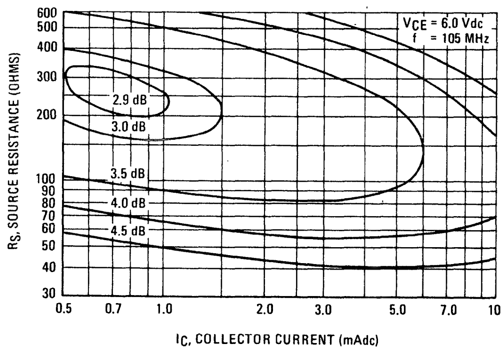



**FIGURE 5 – NOISE FIGURE versus SOURCE RESISTANCE AND COLLECTOR CURRENT**

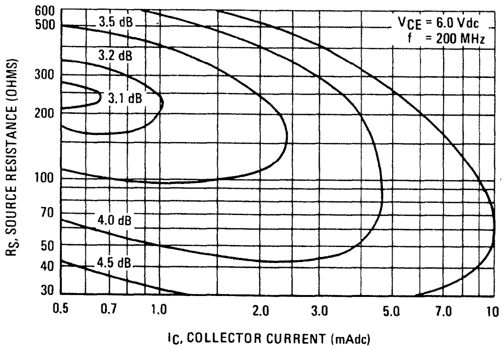


FIGURE 6 – CURRENT-GAIN–BANDWIDTH PRODUCT

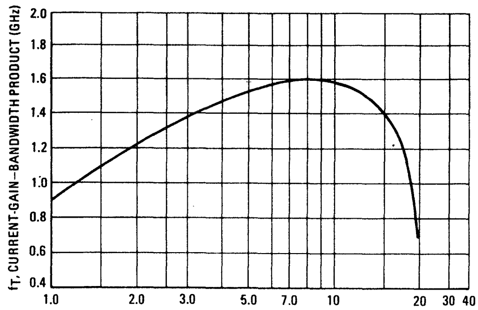



FIGURE 7 – NOISE FIGURE AND POWER GAIN versus COLLECTOR CURRENT

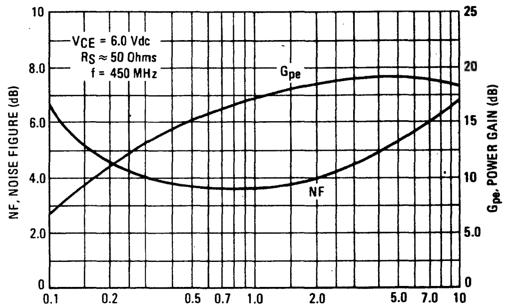



FIGURE 8 – INPUT ADMITTANCE versus FREQUENCY

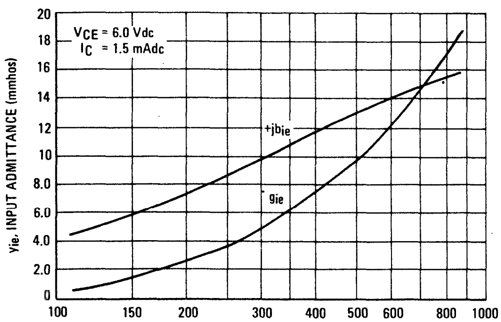



FIGURE 9 – OUTPUT ADMITTANCE versus FREQUENCY

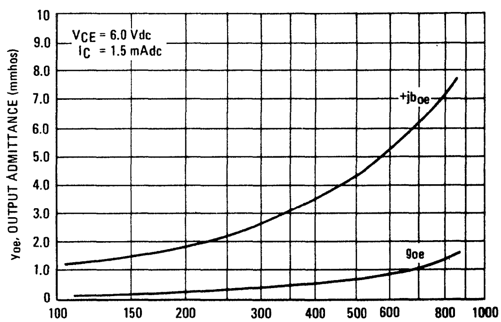



FIGURE 10 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

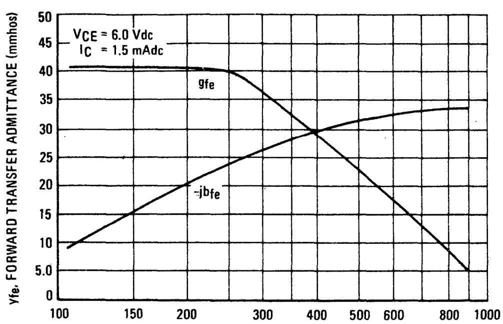



FIGURE 11 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY

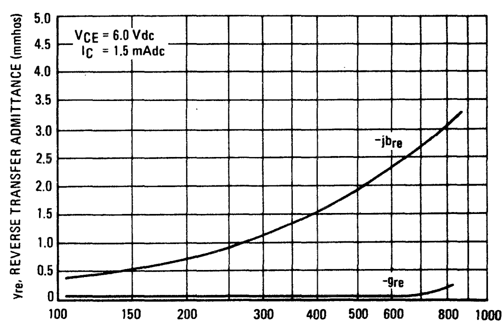



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FIGURE 12 – $S_{11}$, INPUT REFLECTION COEFFICIENT

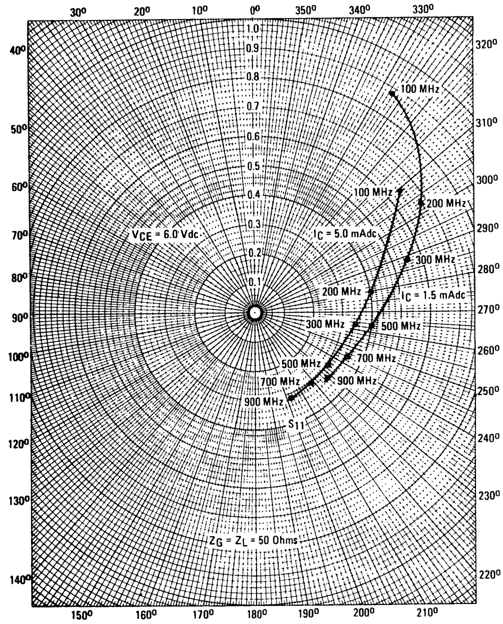



FIGURE 13 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

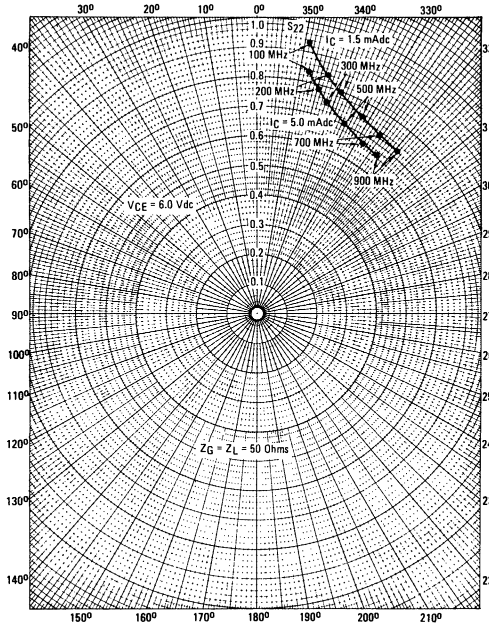



FIGURE 14 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

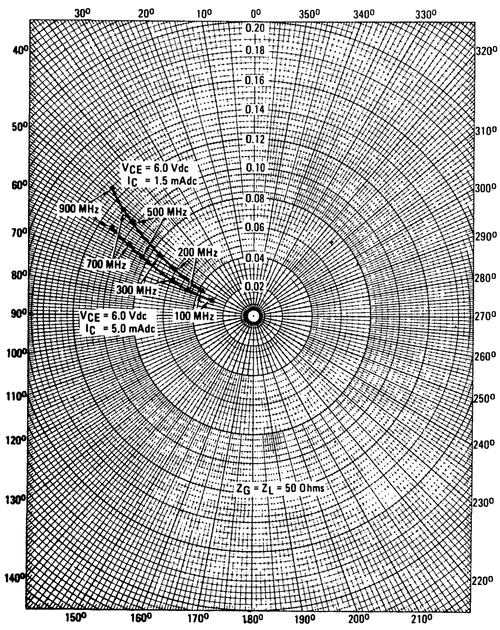



FIGURE 15 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT

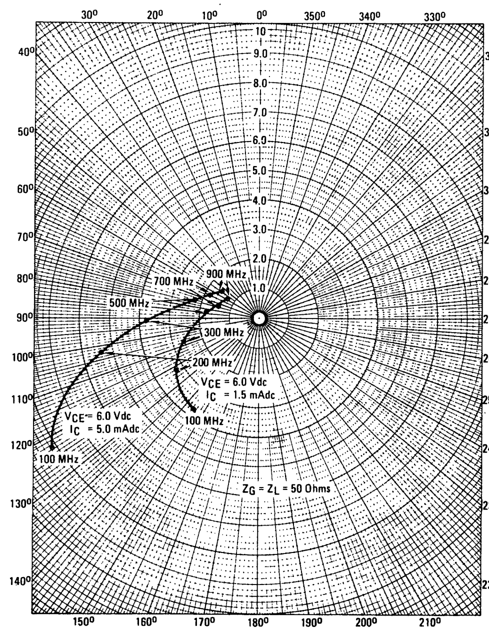
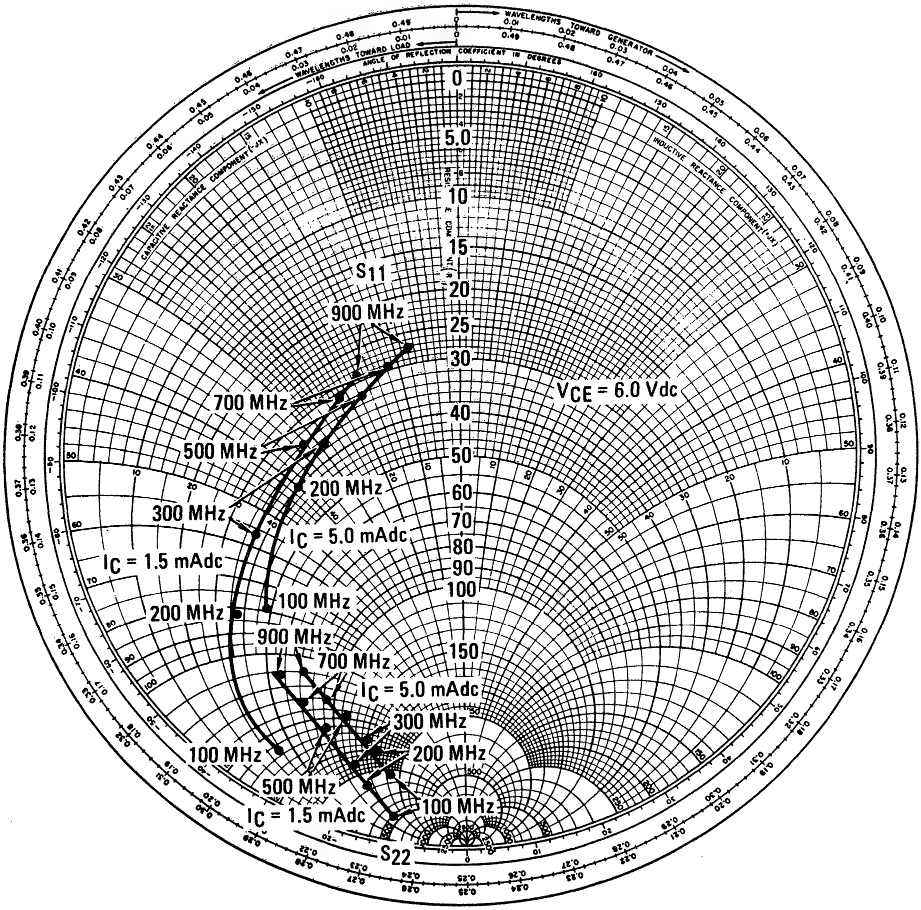


FIGURE 16 – $S_{11}$, INPUT REFLECTION COEFFICIENT AND $S_{22}$, OUTPUT REFLECTION COEFFICIENT

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# MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# 2N4957
# 2N4958
# 2N4959
# 2N5829

## The RF Line

### PNP SILICON HIGH FREQUENCY TRANSISTORS

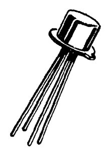
. . . designed for high-gain, low-noise amplifier, oscillator and mixer applications.

- Low Noise Figure @ 450 MHz –
  NF = 2.5 dB (Max) – 2N5829
  = 3.0 dB (Max) – 2N4957
  = 3.3 dB (Max) – 2N4958
  = 3.8 dB (Max) – 2N4959
- High Power Gain @ 450 MHz –
  $G_{pe}$ = 17 dB (Min) – 2N4957, 2N5829
  = 16 dB (Min) – 2N4958
  = 15 dB (Min) – 2N4959
- High Current-Gain–Bandwidth Product –
  $f_T$ = 1.2 GHz (Min) @ $I_E$ = 2.0 mAdc – 2N4957, 2N5829
  = 1.0 GHz (Min) @ $I_E$ = 2.0 mAdc – 2N4958, 2N4959

**1.2 GHz @ 2.0 mAdc – 2N4957, 2N5829**
**1.0 GHz @ 2.0 mAdc – 2N4958, 2N4959**

**HIGH FREQUENCY TRANSISTORS**

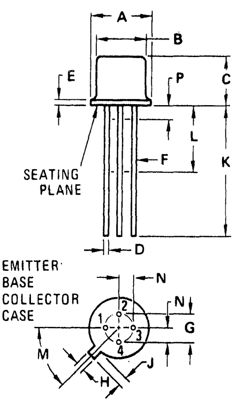
**PNP SILICON**



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 30 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 30 | mAdc |
| Total Power Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.




STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45°BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

**CASE 20-03**
**TO-72**

16

***ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 30 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.1 | μAdc |
| ($V_{CB}$ = 10 Vdc, $I_E$ = 0, $T_A$ = 150°C) | | – | – | 100 | |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | 40 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product (1) ($I_E$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 100 MHz) 2N4957, 2N5829 | $f_T$ | 1200 | 1600 | 2500 | MHz |
| 2N4958, 2N4959 | | 1000 | 1500 | 2500 | |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.4 | 0.8 | pF |
| Small-Signal Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 kHz) | $h_{fe}$ | 20 | – | 200 | – |
| Collector-Base Time Constant ($I_E$ = 2.0 mAdc, $V_{CB}$ = 10 Vdc, f = 63.6 MHz) | $r_b'C_c$ | 1.0 | – | 8.0 | ps |
| Noise Figure ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 450 MHz) 2N5829 | NF | – | 2.3 | 2.5 | dB |
| 2N4957 | | – | 2.6 | 3.0 | |
| 2N4958 | | – | 2.9 | 3.3 | |
| 2N4959 | | – | 3.2 | 3.8 | |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CE}$ = 10 Vdc, $I_C$ = 2.0 mAdc, f = 450 MHz) 2N4957, 2N5829 | $G_{pe}$ | 17 | – | 25 | dB |
| 2N4958 | | 16 | – | 25 | |
| 2N4959 | | 15 | – | 25 | |

*Indicates JEDEC Registered Data.

(1) $f_T$ is defined as the frequency at which $|h_{fe}|$ extrapolates to unity.

FIGURE 1 – NOISE FIGURE AND POWER GAIN TEST CIRCUIT

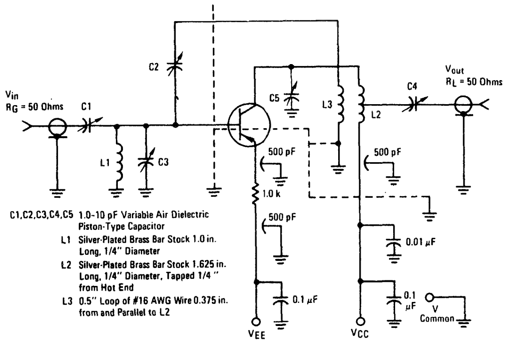



FIGURE 2 – UNILATERALIZED POWER GAIN versus FREQUENCY

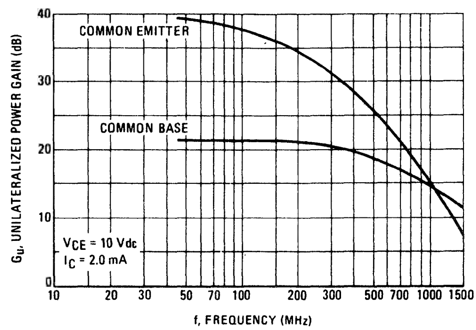



FIGURE 3 – NOISE FIGURE versus FREQUENCY

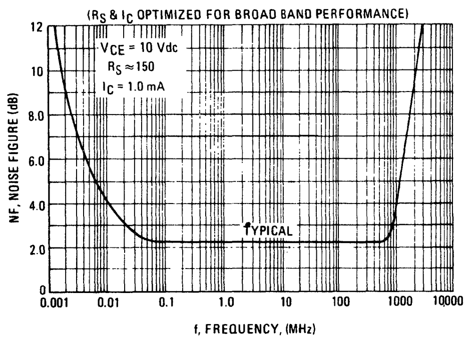



FIGURE 4 – NOISE FIGURE AND POWER GAIN versus COLLECTOR CURRENT

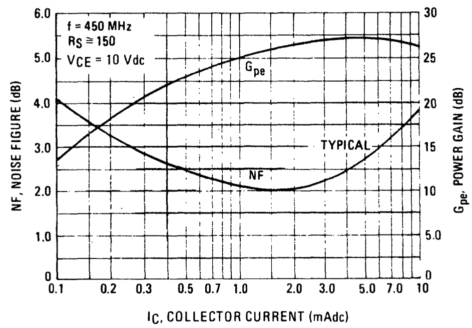



FIGURE 5 – CONTOURS OF NOISE FIGURE versus SOURCE RESISTANCE AND COLLECTOR CURRENT

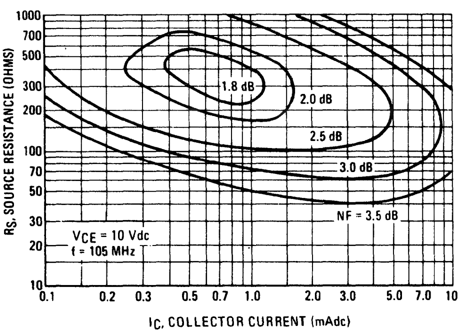
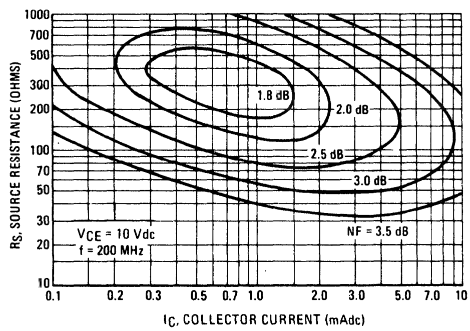



FIGURE 6 – CONTOURS OF NOISE FIGURE versus SOURCE RESISTANCE AND COLLECTOR CURRENT



## COMMON EMITTER CIRCUIT DESIGN DATA

($V_{CE}$ = 10 Vdc, $I_C$ = 2.0 mAdc)

**FIGURE 7 — TRANSDUCER GAIN versus FREQUENCY**

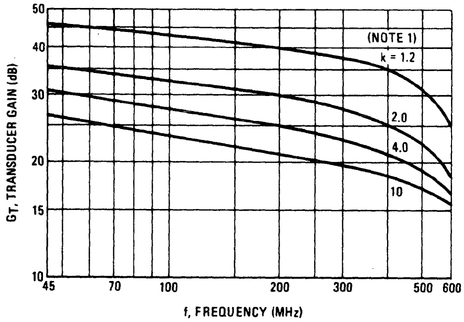



**FIGURE 8 — LINVILL STABILITY FACTOR versus FREQUENCY**

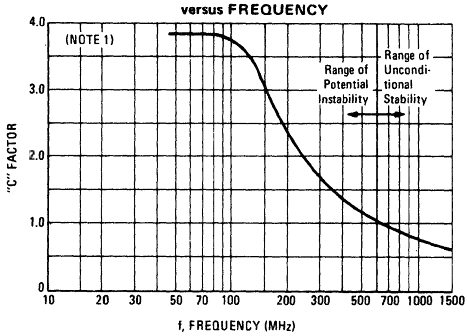



**FIGURE 9 — LOAD ADMITTANCE versus FREQUENCY (REAL)**

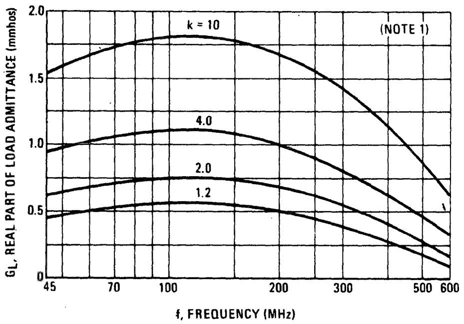



**FIGURE 10 — LOAD ADMITTANCE versus FREQUENCY (IMAGINARY)**

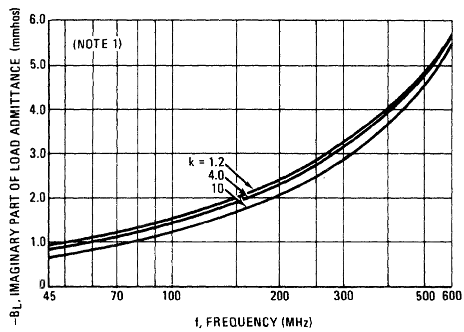



**FIGURE 11 — SOURCE ADMITTANCE versus FREQUENCY (REAL)**

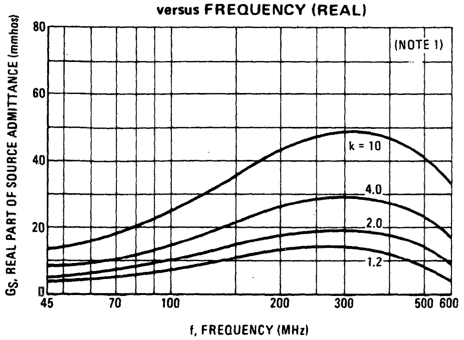
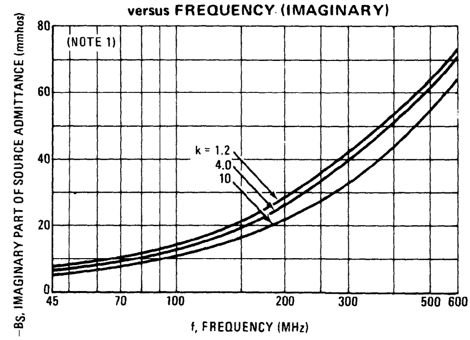



**FIGURE 12 — SOURCE ADMITTANCE versus FREQUENCY (IMAGINARY)**




**NOTE 1**

Figures 7 through 18 are included to assist the circuit designer in determining the stability of his particular circuit. Two stability criteria are given in these figures.

The Linvill "C" factor* is a measure of transistor stability when the input and output are terminated in the worst-case (open circuit) condition. When "C" is less than 1.0, the circuit is unconditionally stable. When "C" is greater than 1.0, the circuit is potentially unstable.

The Stern "K" factor† has been defined to determine the stability of a practical amplifier terminated in finite load and source admittances. If "K" is greater than 1.0, the circuit will be stable. If less than 1.0, the circuit will be unstable. For further details, see Application Note AN-215A.

* "Transistors and Active Circuits," Linvill and Gibbons, McGraw-Hill, 1961.

† "Stability and Power Gain of Tuned Transistor Amplifiers," Artnur P. Stern, Proc. I.R.E., March 1967.

## COMMON BASE CIRCUIT DESIGN DATA

($V_{CB}$ = 10 Vdc, $I_C$ = 2.0 mAdc)

FIGURE 13 – TRANSDUCER GAIN versus FREQUENCY

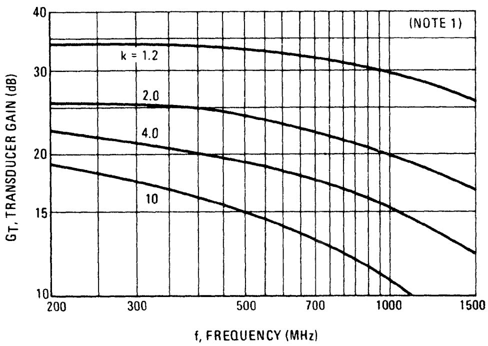



FIGURE 14 – LINVILL STABILITY FACTOR versus FREQUENCY

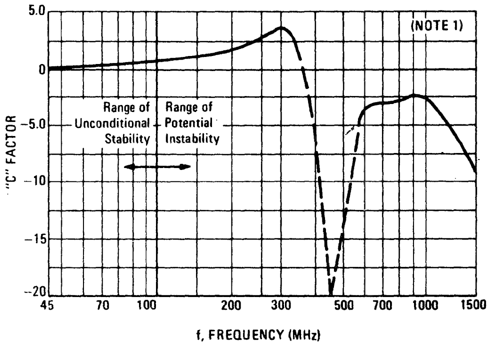



FIGURE 15 – LOAD ADMITTANCE versus FREQUENCY (REAL)

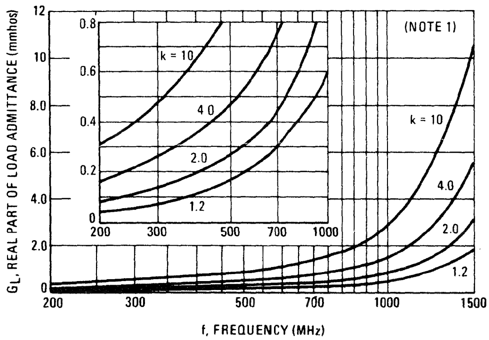



FIGURE 16 – LOAD ADMITTANCE versus FREQUENCY (IMAGINARY)

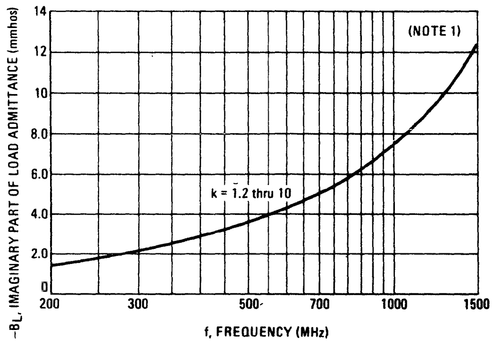



FIGURE 17 – SOURCE ADMITTANCE versus FREQUENCY (REAL)

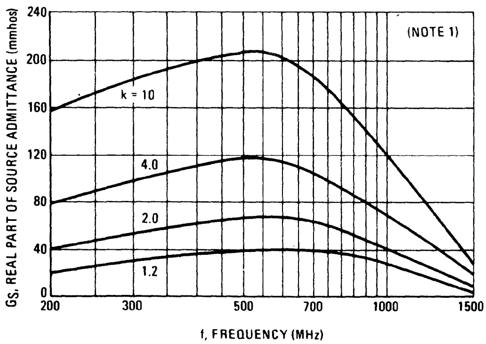



FIGURE 18 – SOURCE ADMITTANCE versus FREQUENCY (IMAGINARY)

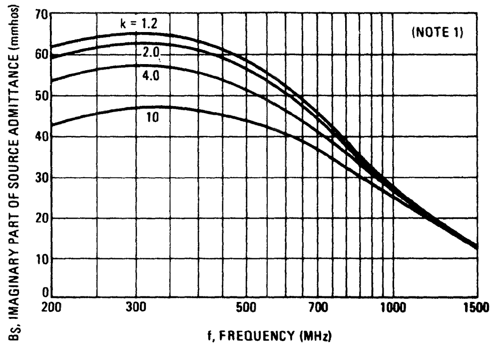


FIGURE 19 – SMALL-SIGNAL CURRENT GAIN versus FREQUENCY

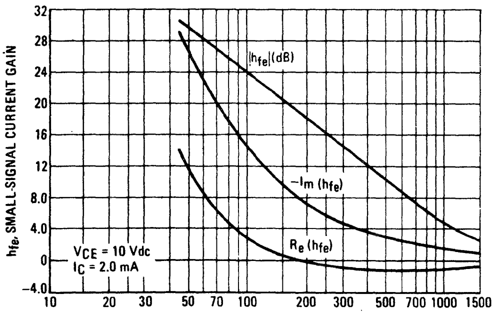



FIGURE 20 – POLAR $h_{fe}$

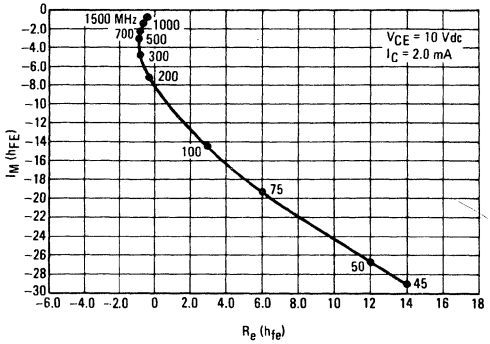



FIGURE 21 – $f_T$ versus COLLECTOR CURRENT

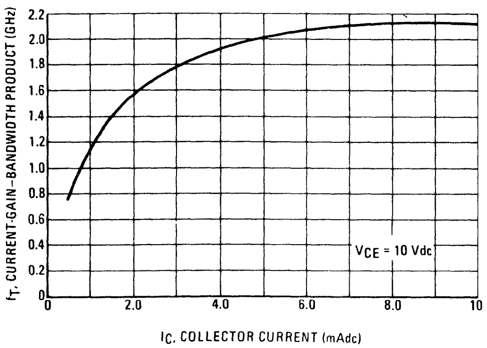



FIGURE 22 – DC CURRENT GAIN

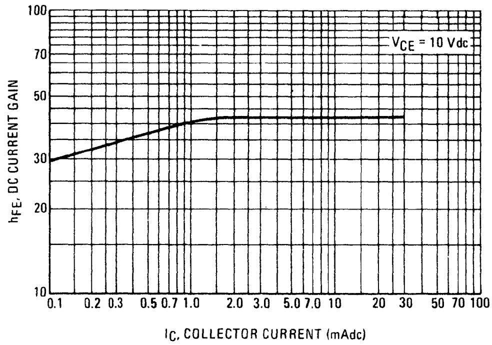



FIGURE 23 – CAPACITANCE

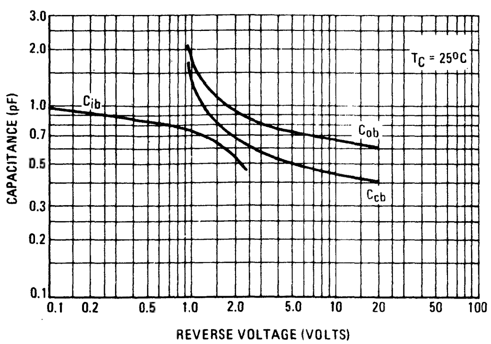
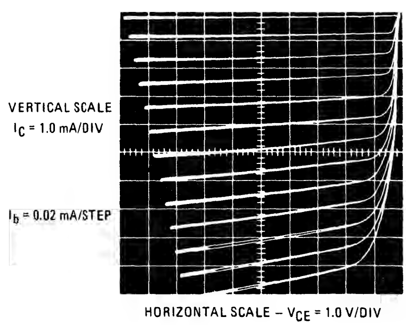
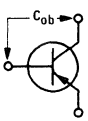
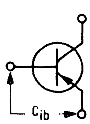



FIGURE 24 – COLLECTOR CHARACTERISTICS

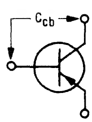



Apply reverse bias between collector and base and measure capacitance between these terminals. Emitter is open.




Apply reverse bias between emitter and base and measure capacitance between these terminals. Collector is open.




Apply reverse bias between collector and base and measure capacitance between these terminals. Emitter is guarded.

## Y PARAMETERS versus CURRENT

(f = 450 MHz)

**COMMON BASE**

$V_{CB}$ = 10 Vdc ——— $V_{CB}$ = 15 Vdc — — —

**COMMON EMITTER**

$V_{CE}$ = 10 Vdc ——— $V_{CE}$ = 15 Vdc — — —

FIGURE 25 – INPUT ADMITTANCE

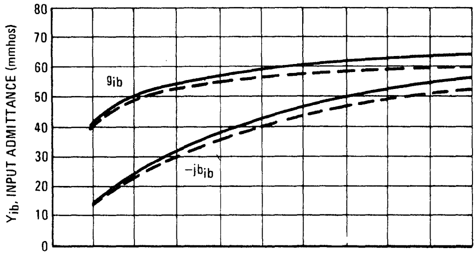



FIGURE 26 – INPUT ADMITTANCE

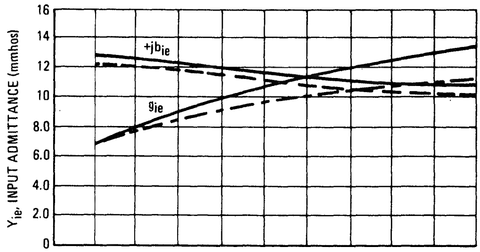



FIGURE 27 – FORWARD TRANSFER ADMITTANCE

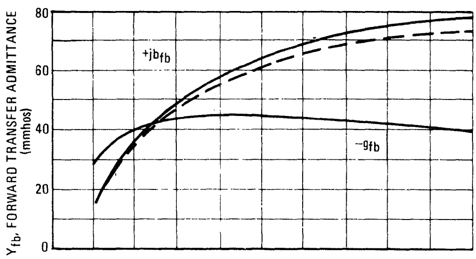



FIGURE 28 – FORWARD TRANSFER ADMITTANCE

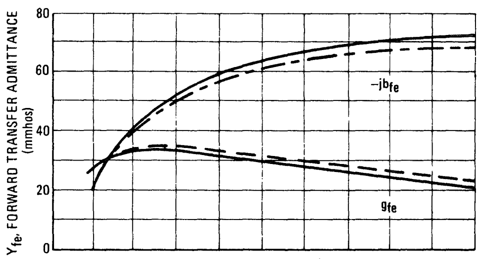



FIGURE 29 – OUTPUT ADMITTANCE

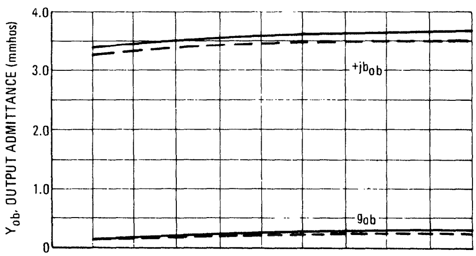



FIGURE 30 – OUTPUT ADMITTANCE

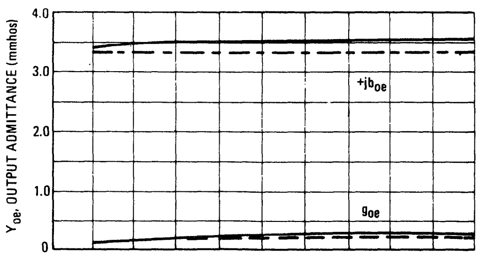



FIGURE 31 – REVERSE TRANSFER ADMITTANCE

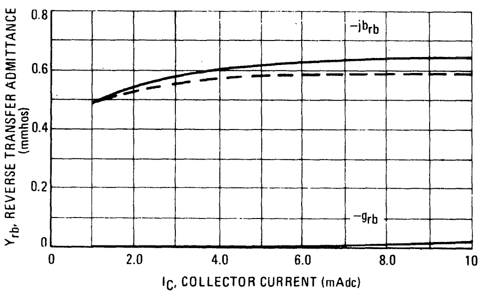
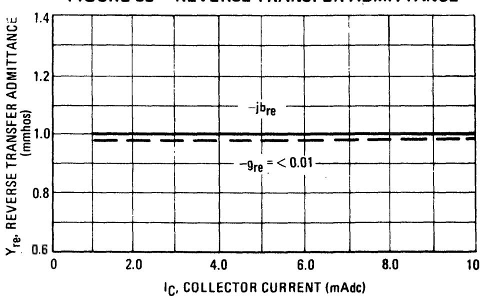



FIGURE 32 – REVERSE TRANSFER ADMITTANCE

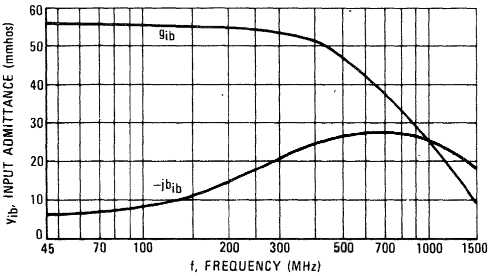


## COMMON BASE y PARAMETER VARIATIONS

($V_{CB}$ = 10 Vdc, $I_C$ = 2.0 mAdc)

### y PARAMETERS versus FREQUENCY

FIGURE 33 – $y_{ib}$ INPUT ADMITTANCE




### POLAR y PARAMETERS versus FREQUENCY

FIGURE 34 – $y_{ib}$ INPUT ADMITTANCE

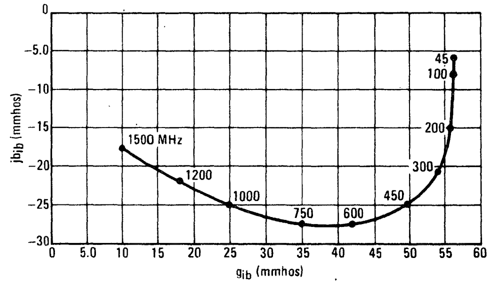



FIGURE 35 – $y_{fb}$ FORWARD TRANSFER ADMITTANCE

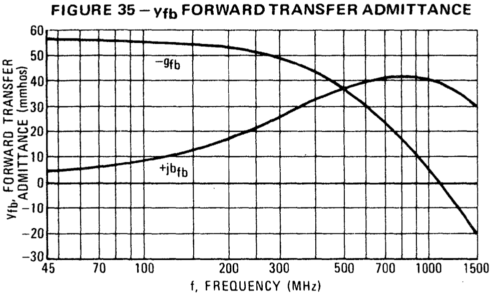



FIGURE 36 – $y_{fb}$ FORWARD TRANSFER ADMITTANCE

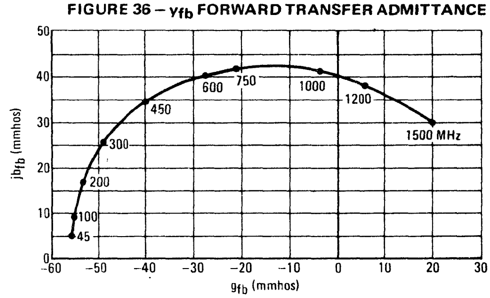



FIGURE 37 – $y_{ob}$ OUTPUT ADMITTANCE

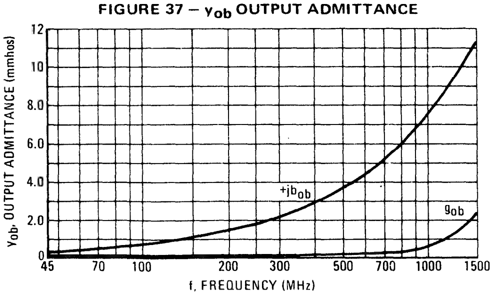



FIGURE 38 – $y_{ob}$ OUTPUT ADMITTANCE

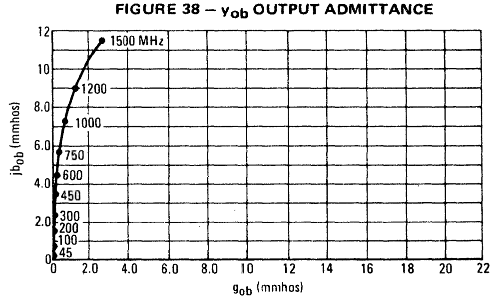



FIGURE 39 – $y_{rb}$ REVERSE TRANSFER ADMITTANCE

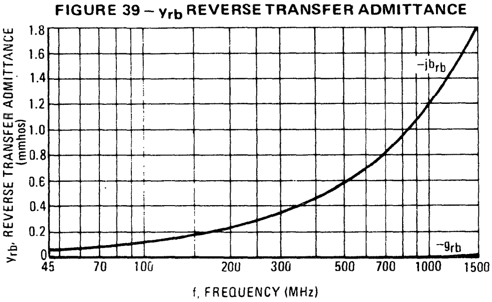
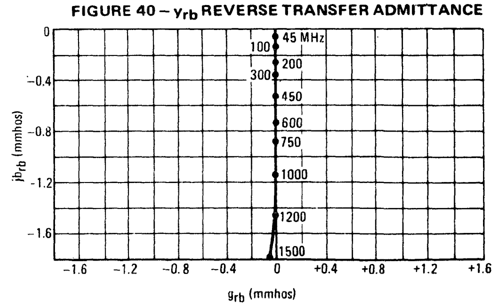



FIGURE 40 – $y_{rb}$ REVERSE TRANSFER ADMITTANCE



## COMMON EMITTER y PARAMETER VARIATIONS

($V_{CE}$ = 10 Vdc, $I_C$ = 2.0 mAdc)

### y PARAMETERS versus FREQUENCY

FIGURE 41 – $y_{ie}$ INPUT ADMITTANCE

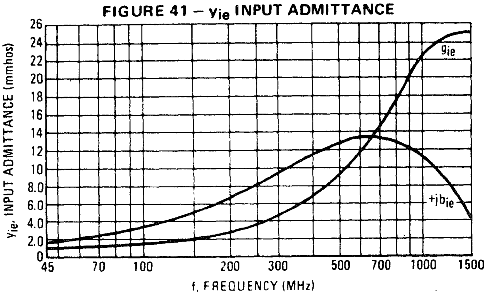



FIGURE 43 – $y_{fe}$ FORWARD TRANSFER ADMITTANCE

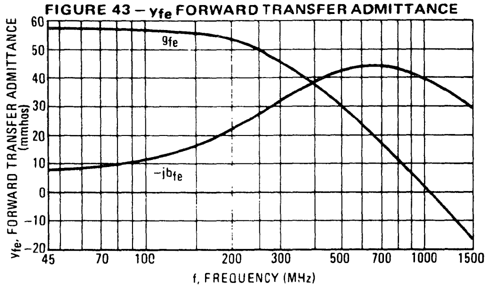



FIGURE 45 – $y_{oe}$ OUTPUT ADMITTANCE

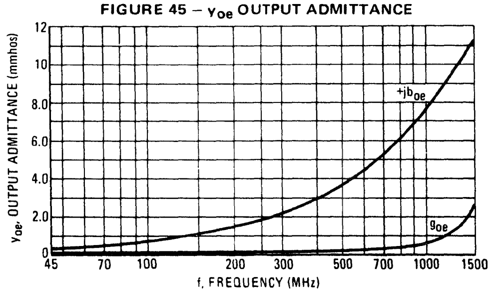
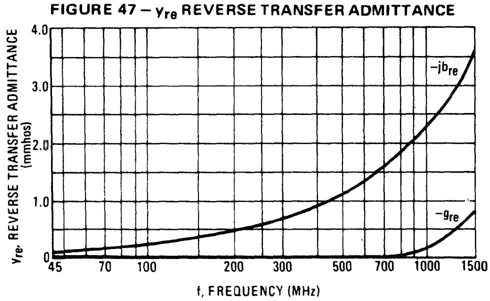



FIGURE 47 – $y_{re}$ REVERSE TRANSFER ADMITTANCE




### POLAR y PARAMETERS versus FREQUENCY

FIGURE 42 – $y_{ie}$ INPUT ADMITTANCE

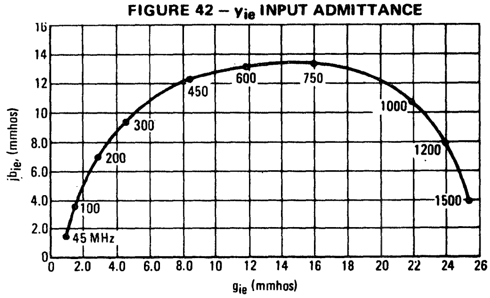



FIGURE 44 – $y_{fe}$ FORWARD TRANSFER ADMITTANCE

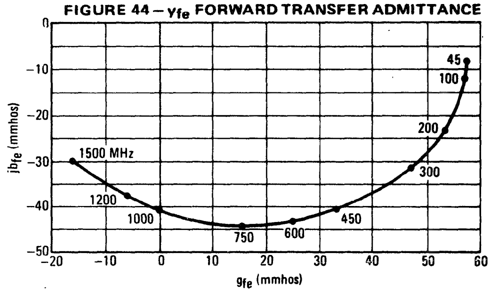



FIGURE 46 – $y_{oe}$ OUTPUT ADMITTANCE

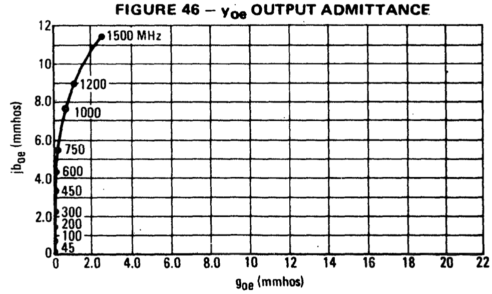
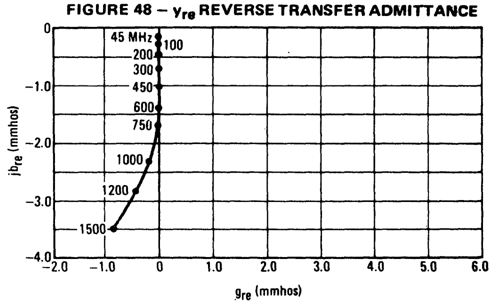



FIGURE 48 – $y_{re}$ REVERSE TRANSFER ADMITTANCE



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# 2N5031
# 2N5032

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTORS

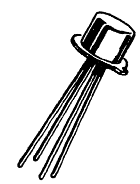
. . . designed primarily for use in high-gain, low-noise, small-signal amplifiers.

- High Current-Gain – Bandwidth Product –
  $f_T$ = 1000 MHz (Min) @ $I_C$ = 5.0 mAdc
- Low Noise Figure @ f = 450 MHz –
  NF = 2.5 dB (Max) – 2N5031
  = 3.0 dB (Max) – 2N5032
- High Power Gain –
  $G_{pe}$ = 14 dB (Min) @ f = 450 MHz

2.5 dB @ 450 MHz – 2N5031
3.0 dB @ 450 MHz – 2N5032

**HIGH FREQUENCY TRANSISTORS**

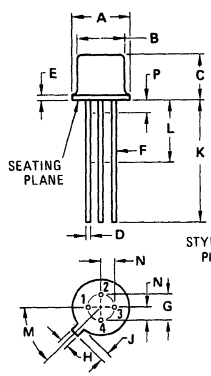
**NPN SILICON**



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 10 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 15 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 20 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.




STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

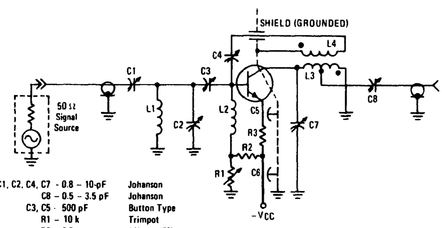
CASE 20-03
TO-72

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| *Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 10 | – | – | Vdc |
| *Collector-Base Breakdown Voltage ($I_C$ = 0.01 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 15 | – | – | Vdc |
| *Emitter-Base Breakdown Voltage ($I_E$ = 0.01 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| *Collector Cutoff Current ($V_{CB}$ = 6.0 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 1.0 | 10 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| *DC Current Gain ($I_C$ = 1.0 mAdc, $V_{CE}$ = 6.0 Vdc) | $h_{FE}$ | 25 | – | 300 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| *Current-Gain—Bandwidth Product ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 100 MHz) | $f_T$ | 1000 | – | 3500 | MHz |
| *Output Capacitance ($V_{CE}$ = 6.0 Vdc, $I_E$ = 0, f = 0.1 MHz) | $C_{cb}$ | – | 1.3 | 1.5 | pF |
| Collector-Base Time Constant ($I_C$ = 6.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 31.8 MHz) | $r_b'C_c$ | – | 5.0 | – | ps |
| *Noise Figure (Figure 1) ($I_C$ = 1.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 450 MHz) | NF | | | | dB |
| 2N5031 | | – | – | 2.5 | |
| 2N5032 | | – | – | 3.0 | |
| **FUNCTIONAL TEST** | | | | | |
| *Common-Emitter Amplifier Power Gain (Figure 1) ($V_{CE}$ = 6.0 Vdc, $I_C$ = 1.0 mAdc, f = 450 MHz) | $G_{pe}$ | 14 | 17 | 25 | dB |

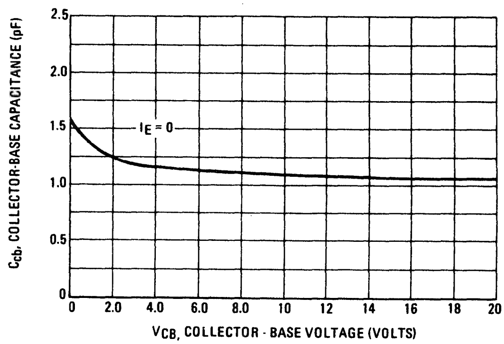
*Indicates JEDEC Registered Data.
(1) Tuned for Minimum Noise.

**FIGURE 1 – POWER GAIN AND NOISE FIGURE TEST CIRCUIT**

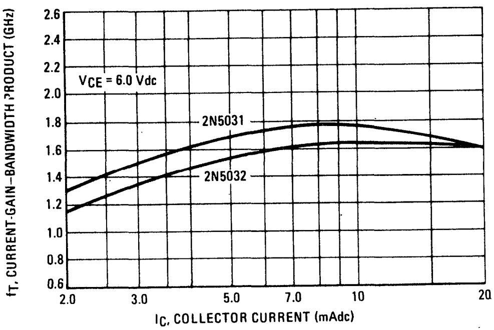



C1, C2, C4, C7 - 0.8 – 10 pF Johanson
C8 – 0.5 – 3.5 pF Johanson
C3, C5 - 500 pF Button Type
R1 – 10 k Trimpot
R2 – 2.7 k 1/4 watt 5%
R3 – 1.0 k 1/4 watt 5%
L1 – 1/4" Brass Rod, Solder Plated, 1-1/8" long. Placed 5/8" from the socket and in parallel with the shield, which bisects the socket. The ungrounded side is soldered directly to the ungrounded side of C2.
L2 – 0.22 μH
L3 – 1/4" Brass Rod, Solder Plated, 1-1/2" long. Placed 1/2" from the socket and in parallel with shield, which bisects the socket. The ungrounded side is soldered directly to the ungrounded side of C7. Output tap is 15/16" from ground.
L4 – 1/2 Turn #16, 5/16" above L3 and 5/8" long, (over L3).

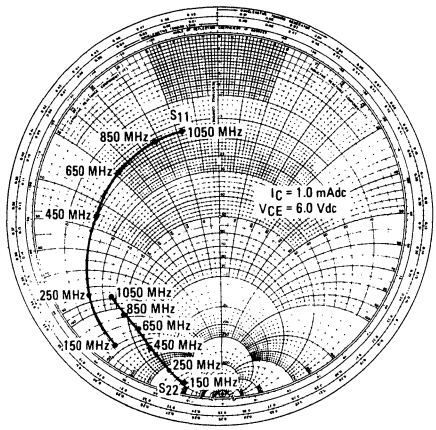
**FIGURE 2 – COLLECTOR-BASE CAPACITANCE versus VOLTAGE**



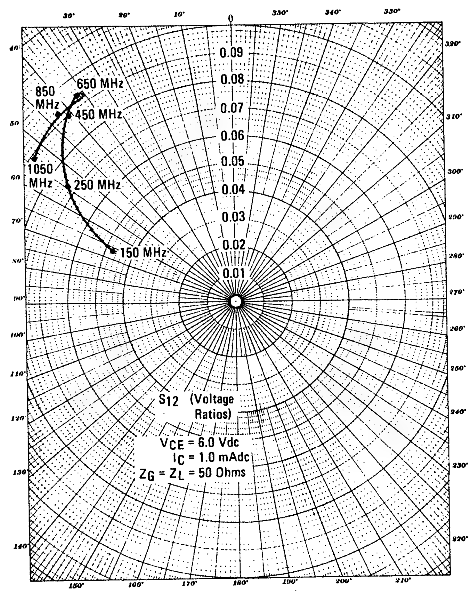
### FIGURE 3 – CURRENT-GAIN–BANDWIDTH PRODUCT




### FIGURE 4 – $S_{11}$ AND $S_{22}$




### FIGURE 5 – $S_{12}$




### FIGURE 6 – $S_{21}$

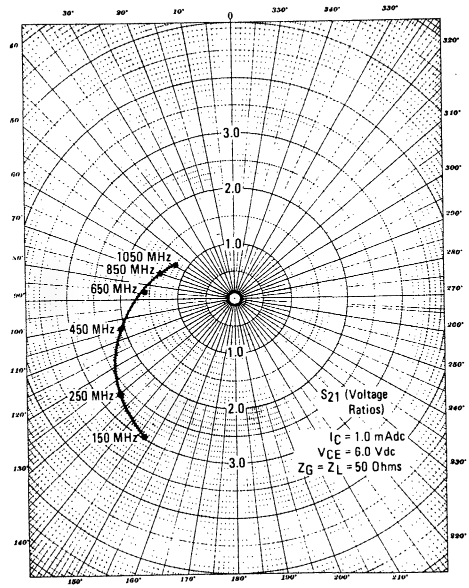


FIGURE 7 – NOISE FIGURE versus FREQUENCY

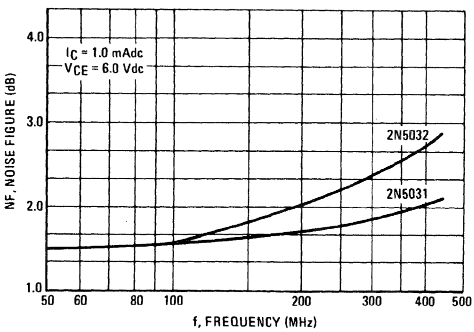



FIGURE 8 – POWER GAIN versus FREQUENCY

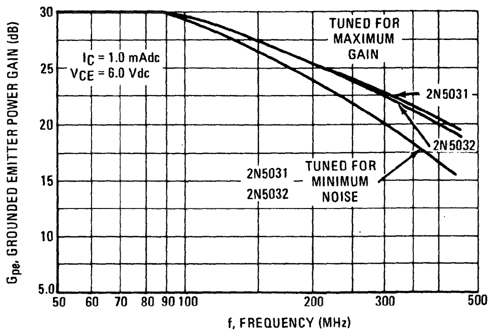



FIGURE 9 – INPUT ADMITTANCE versus FREQUENCY

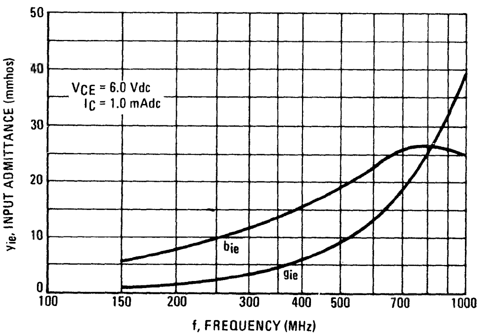



FIGURE 10 – OUTPUT ADMITTANCE versus FREQUENCY

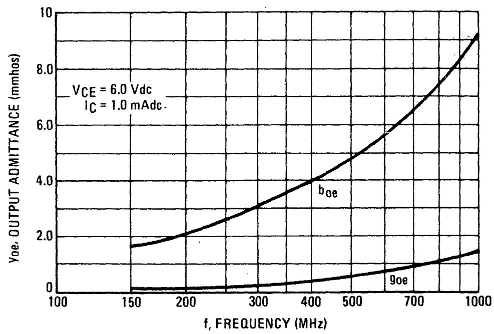



FIGURE 11 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

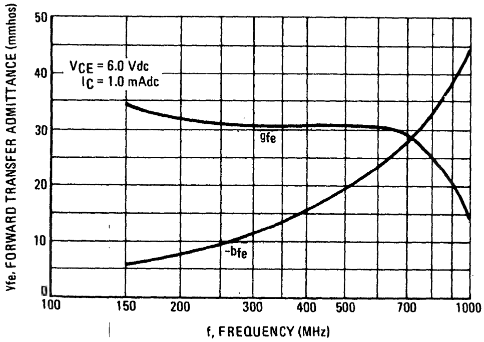
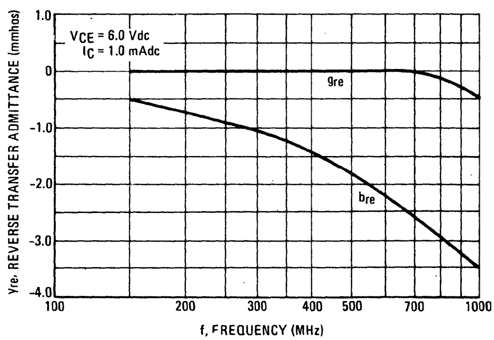



FIGURE 12 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5108

## The RF Line

**1.0 W - 1 GHz**

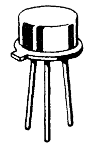
**HIGH FREQUENCY TRANSISTOR**

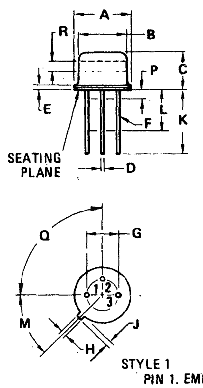
**NPN SILICON**

## NPN SILICON HIGH-FREQUENCY TRANSISTOR

. . . designed for amplifier, frequency multiplier, or oscillator applications in military and industrial equipment. Suitable for use as output, driver, or pre-driver stages in UHF equipment and as a fundamental frequency oscillator at 1.68 GHz.

- Specified 1 GHz, 28 Vdc Characteristics –
  Output Power = 1.0 Watt
  Minimum Gain = 5.0 dB
  Efficiency = 35%
- Typical 1.68 GHz, 28 Vdc Characteristics –
  Output Power = 0.3 Watt
  Efficiency = 15%






STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| *Collector-Emitter Voltage ($R_{BE}$ = 10 Ohms) | $V_{CER}$ | 55 | Vdc |
| *Collector-Base Voltage | $V_{CB}$ | 55 | Vdc |
| *Emitter-Base Voltage | $V_{EB}$ | 3.0 | Vdc |
| *Collector Current – Continuous | $I_C$ | 0.4 | Adc |
| *Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 3.5<br>0.02 | Watts<br>W/°C |
| *Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

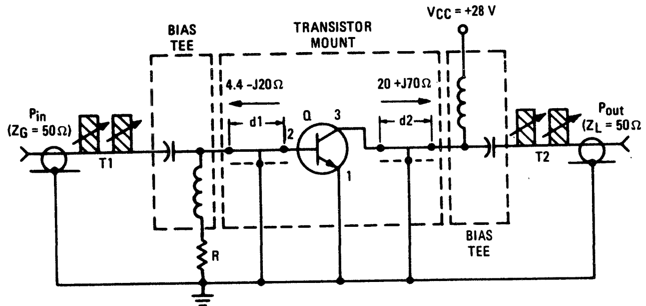
*Indicates JEDEC Registered Data.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| *Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 10 ohms) | $V_{CER(sus)}$ | 55 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 55 | – | – | Vdc |
| *Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| *Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 20 | μAdc |
| *Collector Cutoff Current ($V_{CE}$ = 50 Vdc, $V_{BE}$ = 0) ($V_{CE}$ = 15 Vdc, $V_{BE}$ = 0, $T_C$ = 150°C) | $I_{CES}$ | – <br> – | – <br> – | 1.0 <br> 10 | μAdc <br> mAdc |
| **ON CHARACTERISTICS** | | | | | |
| Collector-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 10 mAdc) | $V_{CE(sat)}$ | – | – | 0.5 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| *Current-Gain—Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 1200 | – | – | MHz |
| *Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 1.3 | 3.0 | pF |
| **FUNCTIONAL TEST** | | | | | |
| *Common-Emitter Amplifier Power Gain (Figure 1) ($P_{out}$ = 1.0 W, $V_{CC}$ = 28 Vdc, $I_C$ = 102 mAdc, f = 1.0 GHz) | $G_{PE}$ | 5.0 | – | – | dB |
| Power Output (Figure 1) ($P_{in}$ = 316 mW, $V_{CE}$ = 28 Vdc, f = 1.0 GHz) | $P_{out}$ | 1.0 | – | – | Watt |
| *Collector Efficiency ($P_{in}$ = 316 mW, $V_{CE}$ = 28 Vdc, f = 1.0 GHz) | $\eta$ | 35 | – | – | % |
| Power Output (Oscillator) (Figure 2) ($V_{CE}$ = 20 Vdc, $V_{EB}$ = 1.5 Vdc, f = 1.68 GHz) (Minimum Efficiency = 15%) | $P_{out}$ | – | 0.3 | – | Watt |

*Indicates JEDEC Registered Data.

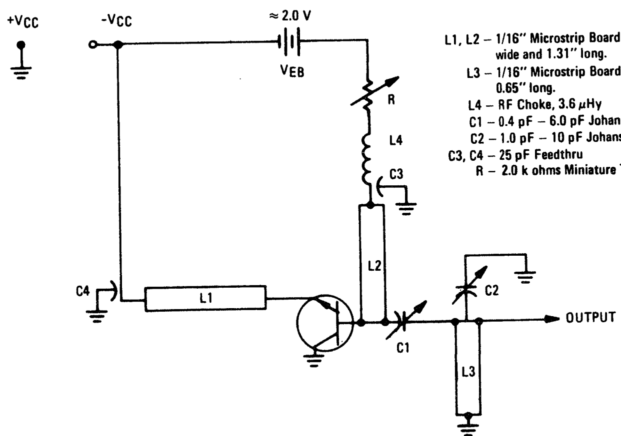
**FIGURE 1 – 1 GHz RF AMPLIFIER OUTPUT POWER TEST CIRCUIT**




d1: 1" Input line, center conductor width = 0.280"
d2: 1" Output line, center conductor width = 0.125"
Q: 2N5108
R: 3.9 ohms
T1, T2: Microlab Double Stub Tuner, or Equivalent
Bias Tee: Microlab 08N, or Equivalent
Transistor Mount: 1/32" Microstrip board

Note: Impedance measurements are made at transistor socket pins.

**FIGURE 2 – 1.68 GHz RF OSCILLATOR OUTPUT POWER TEST CIRCUIT**




L1, L2 – 1/16" Microstrip Board. Lines are 0.16" wide and 1.31" long.
L3 – 1/16" Microstrip Board. 0.16" wide and 0.65" long.
L4 – RF Choke, 3.6 μHy
C1 – 0.4 pF – 6.0 pF Johanson 4640
C2 – 1.0 pF – 10 pF Johanson 4355
C3, C4 – 25 pF Feedthru
R – 2.0 k ohms Miniature Trim pot

FIGURE 3 – OUTPUT POWER versus INPUT POWER

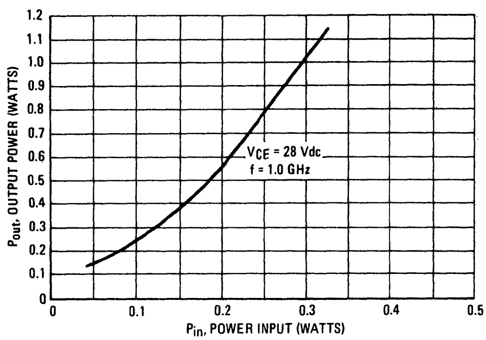



FIGURE 4 – OUTPUT POWER versus FREQUENCY

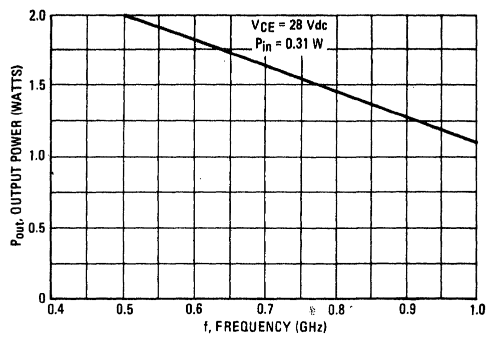



FIGURE 5 – OUTPUT POWER versus COLLECTOR-EMITTER VOLTAGE

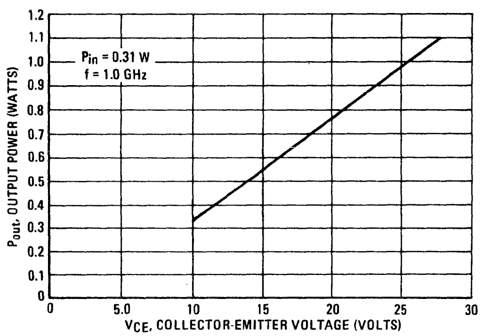



FIGURE 6 – OSCILLATOR OUTPUT POWER versus COLLECTOR CURRENT

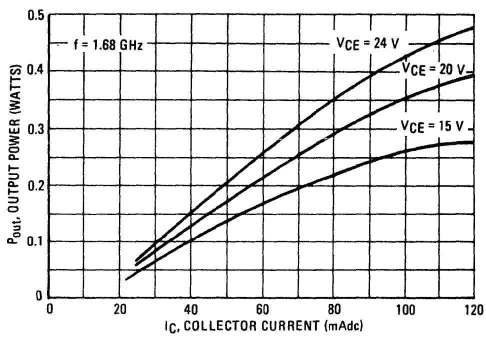



FIGURE 7 CURRENT-GAIN–BANDWIDTH PRODUCT versus CURRENT

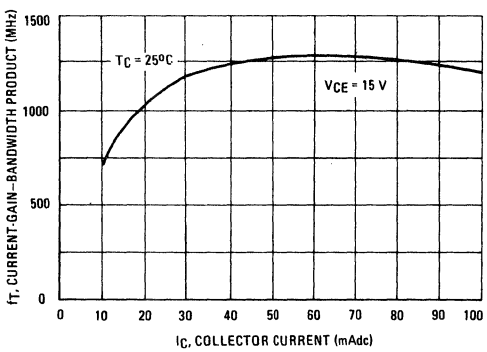
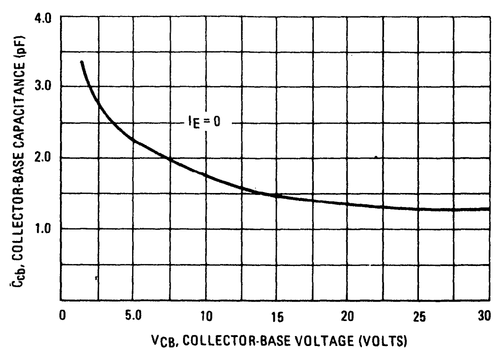



FIGURE 8 COLLECTOR BASE CAPACITANCE versus VOLTAGE



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5109

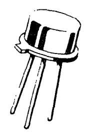
## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTOR

. . . designed specifically for broadband applications requiring good linearity. Useable as a high frequency current mode switch to 200 mA.

- Low Noise Figure — @ f = 200 MHz
  NF = 3.0 dB (Typ)
- High Current-Gain — Bandwidth Product —
  $f_T$ = 1200 MHz (Min) @ $I_C$ = 50 mAdc

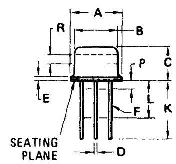
**1.2 GHz @ 50 mAdc**
**HIGH FREQUENCY TRANSISTOR**
**NPN SILICON**

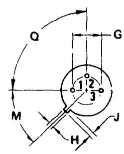


### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Base Current — Continuous | $I_B$ | 400 | mAdc |
| Collector Current — Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_C$ = 75°C (1)<br>Derate above 25°C | $P_D$ | 2.5<br>20 | Watt<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

(1) Total Device Dissipation at $T_A$ = 25°C is 1.0 Watt.
* Indicates JEDEC Registered Data.



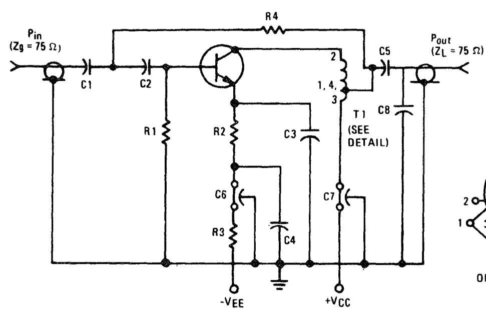

STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

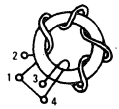
| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

**CASE 79-02**
**TO-39**

**FIGURE 1 — RF AMPLIFIER FOR VOLTAGE GAIN TEST CIRCUIT**




DETAIL
OF TRANSFORMER

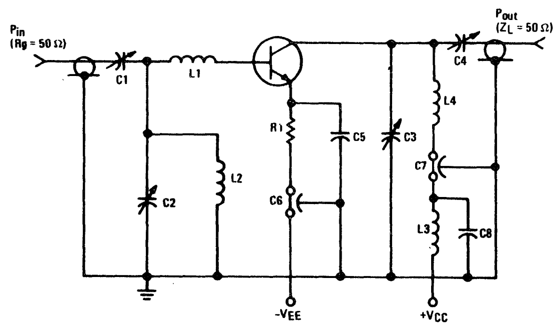
C1, C2, C3, C5 0.002 μF
C4 0.03 μF
C6, C7 1500 pF
C8 18 pF
R1 4.7 k, 1/4 W
R2 6.8 Ω, 1/2 W
R3 330 Ω, 1 W
R4 200 Ω, 1/4 W
T1 4 Turns #30 Wire
Bifilar wound on "Indiana General" Core #CF-102-Q1, or equivalent

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| ***OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 20 | – | – | Vdc |
| Collector-Emitter Sustaining Voltage (1) ($I_C$ = 5.0 mAdc, $R_{BE}$ = 10 Ω) | $V_{CER(sus)}$ | 40 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 20 | μAdc |
| Collector Cutoff Current<br>($V_{CE}$ = 15 Vdc, $V_{BE}$ = −1.5 V, $T_C$ = 150°C)<br>($V_{CE}$ = 35 Vdc, $V_{BE}$ = −1.5 V) | $I_{CEX}$ | –<br>– | –<br>– | 5.0<br>5.0 | mAdc<br>mAdc |
| Emitter Cutoff Current ($V_{BE}$ = 3.0 Vdc, $I_C$ = 0) | $I_{EBO}$ | – | – | 100 | μAdc |
| ***ON CHARACTERISTICS** | | | | | |
| DC Current Gain<br>($I_C$ = 360 mAdc, $V_{CE}$ = 5.0 Vdc)<br>($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc) | $h_{FE}$ | <br>5.0<br>40 | <br>–<br>– | <br>–<br>120 | <br>–<br>– |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| *Current-Gain – Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 1200 | – | – | MHz |
| *Collector-Base Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 1.8 | 3.5 | pF |
| Noise Figure ($I_C$ = 10 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) (Figure 2) | NF | – | 3.0 | – | dB |
| **FUNCTIONAL TEST** | | | | | |
| *Common-Emitter Amplifier Voltage Gain (Figure 1) ($I_C$ = 50 mAdc, $V_{CC}$ = 15 Vdc, f = 50 to 216 MHz) | $G_{ve}$ | 11 | – | – | dB |
| *Power Input (Figure 2) ($I_C$ = 50 mAdc, $V_{CC}$ = 15 Vdc, $R_S$ = 50 ohms, $P_{out}$ = 1.26 mW, f = 200 MHz) | $P_{in}$ | – | – | 0.1 | mW |

*Indicates JEDEC Registered Data.
(1) Pulsed thru a 25 mH Inductor; 50% Duty Cycle

FIGURE 2 – 200 MHz TEST CIRCUIT




C1, C2, C3 1.0 – 30 pF
C4 1.0 – 20 pF
C5 10,000 pF
C6, C7 1,000 pF
C8 0.01 μF

L1 4-1/2 turns, No. 22 wire, 3/16" I.D.
L4 3-1/2 turns, No. 22 wire, 3/16" I.D.
L2, L3 0.82 μH RFC
R1 240 OHMS, 2 WATTS

FIGURE 3 – CURRENT-GAIN – BANDWIDTH PRODUCT

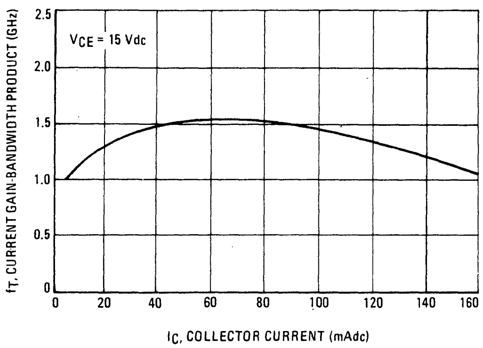



FIGURE 4 – COLLECTOR-BASE TIME CONSTANT

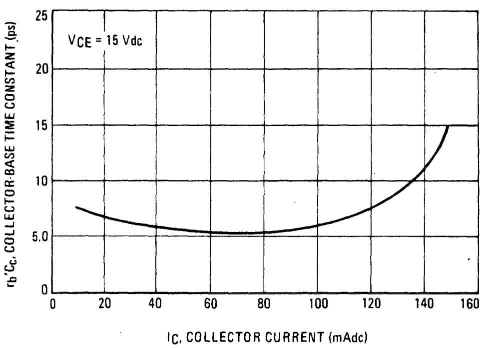



FIGURE 5 – SATURATION VOLTAGES

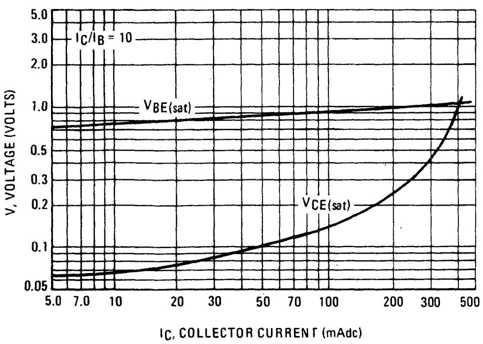



FIGURE 6 – CAPACITANCES versus REVERSE VOLTAGE

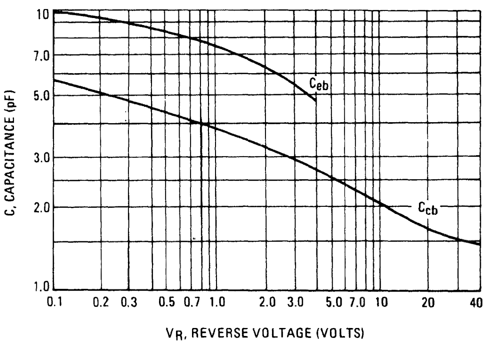


FIGURE 7 – INPUT ADMITTANCE versus FREQUENCY

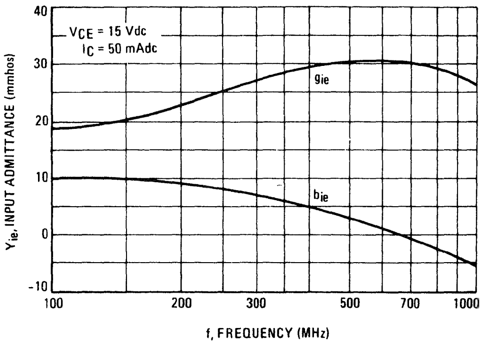



FIGURE 8 – INPUT ADMITTANCE versus COLLECTOR CURRENT

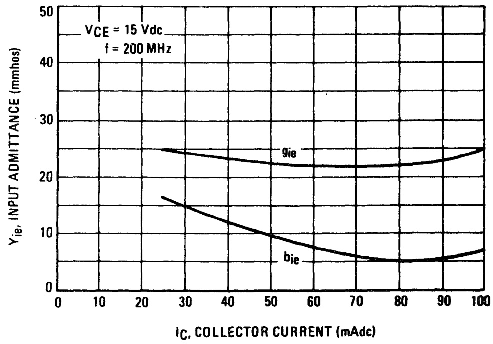



FIGURE 9 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY

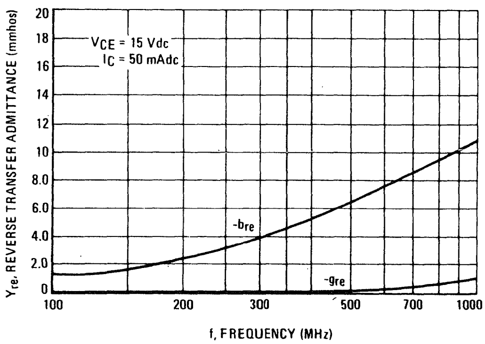



FIGURE 10 – REVERSE TRANSFER ADMITTANCE versus COLLECTOR CURRENT

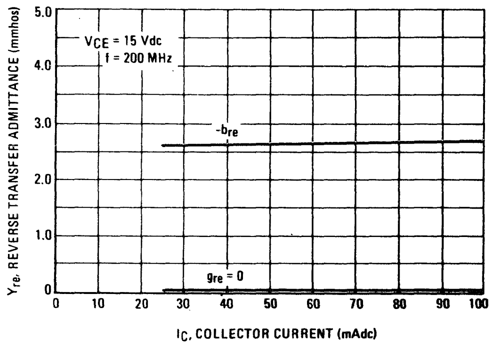



FIGURE 11 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

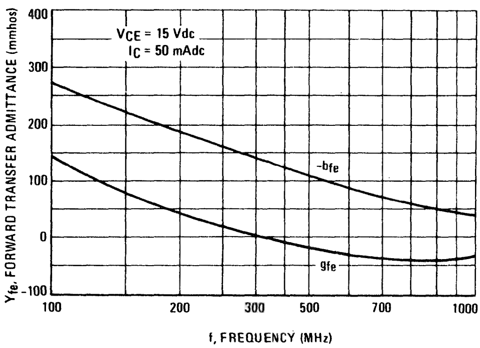



FIGURE 12 – FORWARD TRANSFER ADMITTANCE versus COLLECTOR CURRENT

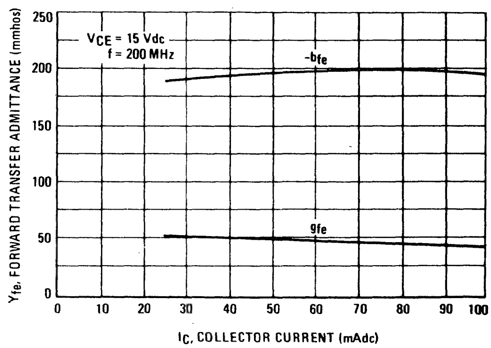


FIGURE 13 – OUTPUT ADMITTANCE versus FREQUENCY

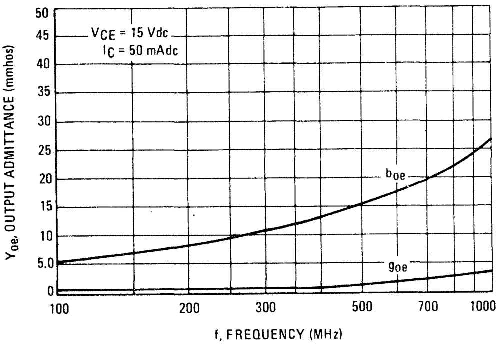



FIGURE 14 – OUTPUT ADMITTANCE versus COLLECTOR CURRENT

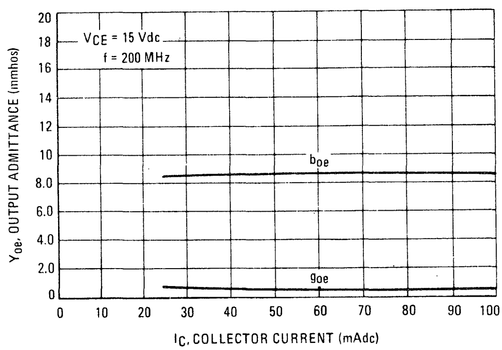



FIGURE 15 – INPUT REFLECTION COEFFICIENT versus FREQUENCY

FIGURE 16 – OUTPUT REFLECTION COEFFICIENT versus FREQUENCY

FIGURE 15 – INPUT REFLECTION COEFFICIENT versus FREQUENCY

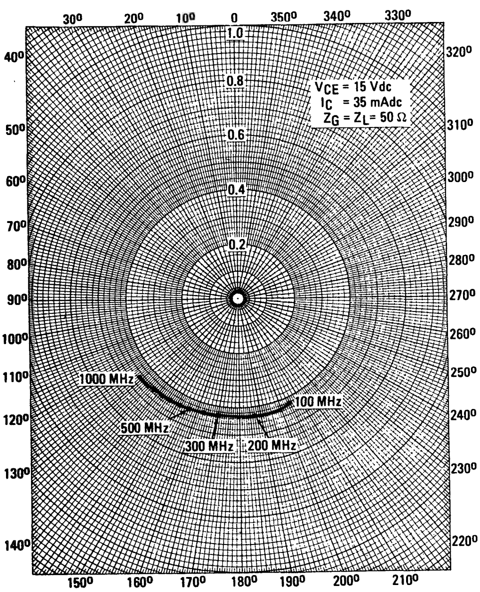



FIGURE 16 – OUTPUT REFLECTION COEFFICIENT versus FREQUENCY

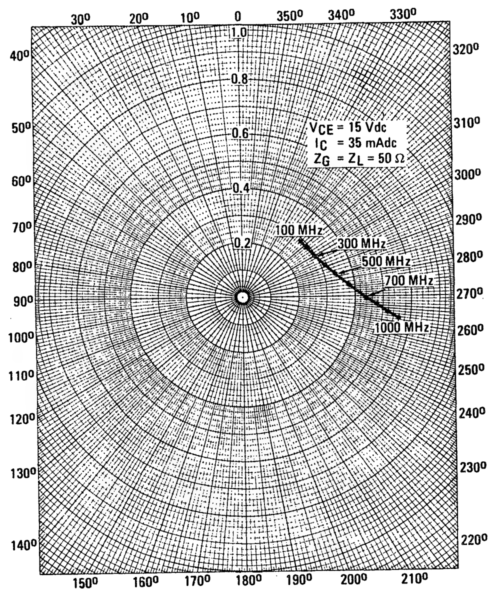


FIGURE 17 – REVERSE TRANSMISSION COEFFICIENT versus FREQUENCY

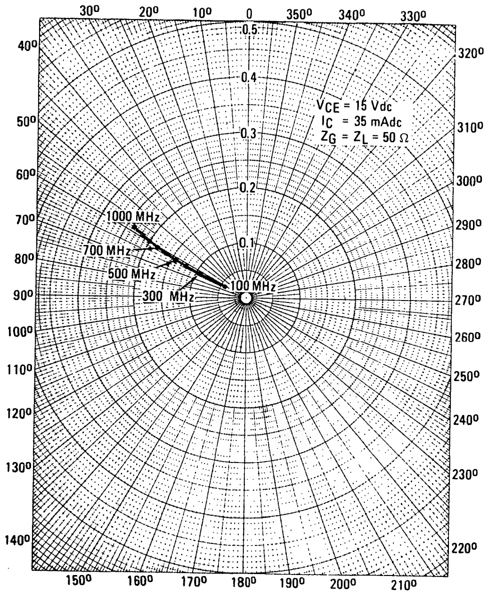



FIGURE 18 – FORWARD TRANSMISSION COEFFICIENT versus FREQUENCY

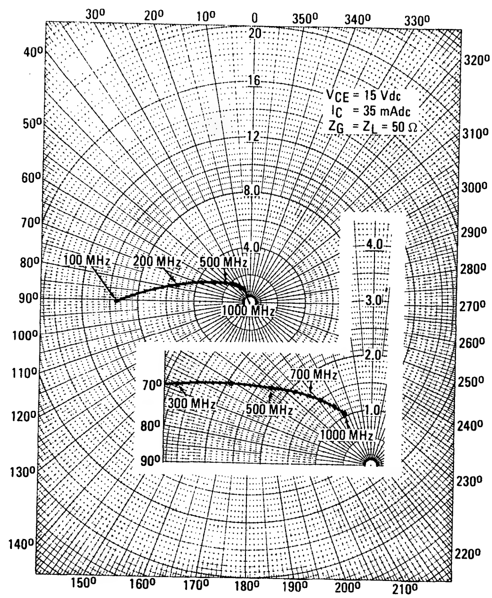
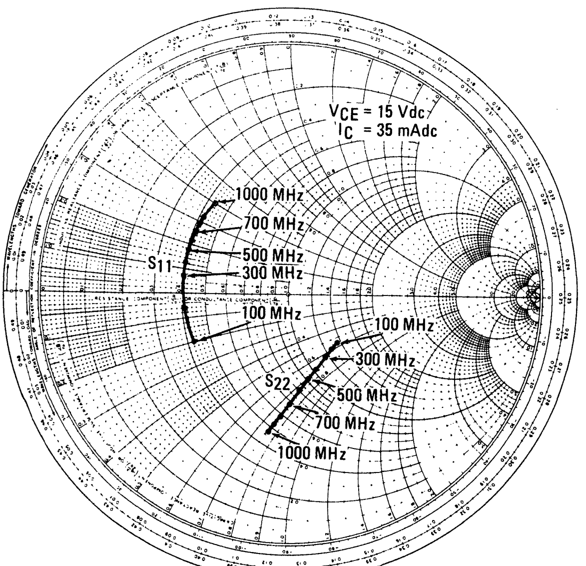



FIGURE 19 – INPUT REFLECTION COEFFICIENT AND OUTPUT REFLECTION COEFFICIENT versus FREQUENCY



**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5179

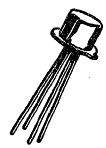
## The RF Line

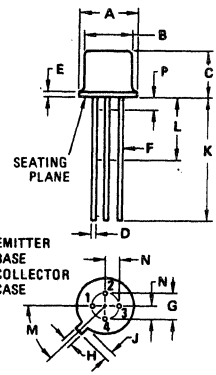
4.5 dB @ 200 MHz
**HIGH FREQUENCY TRANSISTOR**
**NPN SILICON**

## NPN SILICON RF HIGH FREQUENCY TRANSISTOR

. . . designed primarily for use in high-gain, low-noise amplifier, oscillator, and mixer applications. Can also be used in UHF converter applications.

- High Current-Gain – Bandwidth Product –
  $f_T$ = 1.4 GHz (Typ) @ $I_C$ = 10 mAdc
- Low Collector-Base Time Constant –
  $r_b'C_c$ = 14 ps (Max) @ $I_E$ = 2.0 mAdc
- Characterized with Scattering Parameters
- Low Noise Figure –
  NF = 4.5 dB (Max) @ f = 200 MHz






STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

CASE 20-03
TO-72

## *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage<br>Applicable 1.0 to 20 mAdc | $V_{CEO}$ | 12 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 2.5 | Vdc |
| Collector Current | $I_C$ | 50 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 300<br>1.71 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

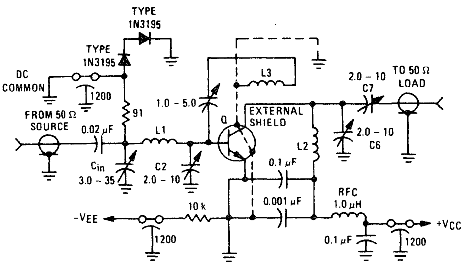
*Indicates JEDEC Registered D

*ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 3.0 mAdc, $I_B$ = 0) | $V_{CEO(sus)}$ | 12 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.001 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 20 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.01 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 2.5 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) ($V_{CB}$ = 15 Vdc, $I_E$ = 0, $T_A$ = 150°C) | $I_{CBO}$ | – <br> – | 0.02 <br> 1.0 | μAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 3.0 mAdc, $V_{CE}$ = 1.0 Vdc) | $h_{FE}$ | 25 | 250 | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 10 mAdc, $I_B$ = 1.0 mAdc) | $V_{CE(sat)}$ | – | 0.4 | Vdc |
| Base-Emitter Saturation Voltage ($I_C$ = 10 mAdc, $I_B$ = 1.0 mAdc) | $V_{BE(sat)}$ | – | 1.0 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain – Bandwidth Product (1) ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 100 MHz) | $f_T$ | 900 | 2000 | MHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | $C_{cb}$ | – | 1.0 | pF |
| Small-Signal Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 1.0 kHz) | $h_{fe}$ | 25 | 300 | – |
| Collector-Base Time Constant ($I_E$ = 2.0 mAdc, $V_{CB}$ = 6.0 Vdc, f = 31.9 MHz) | $r_b'C_c$ | 3.0 | 14 | ps |
| Noise Figure (See Figure 1) ($I_C$ = 1.5 mAdc, $V_{CE}$ = 6.0 Vdc, $R_S$ = 50 ohms, f = 200 MHz) | NF | – | 4.5 | dB |
| **FUNCTIONAL TEST** | | | | |
| Common-Emitter Amplifier Power Gain (See Figure 1) ($V_{CE}$ = 6.0 Vdc, $I_C$ = 5.0 mAdc, f = 200 MHz) | $G_{pe}$ | 15 | – | dB |
| Power Output (See Figure 2) ($V_{CB}$ = 10 Vdc, $I_E$ = 12 mAdc, f≥500 MHz) | $P_{out}$ | 20 | – | mW |

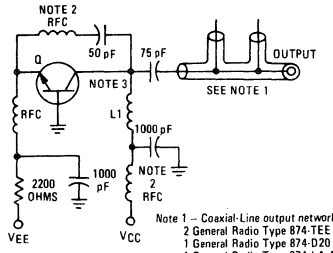
*Indicates JEDEC Registered Values.
(1) $f_T$ is defined as the frequency at which $|h_{fe}|$ extrapolates to unity.

FIGURE 1 – 200 MHz AMPLIFIER POWER GAIN AND NOISE FIGURE CIRCUIT




L1 1-3/4 Turns, #18 AWG, 0.5" L, 0.5" Diameter
L2 2 Turns, #16 AWG, 0.5" L, 0.5" Diameter
L3 2 Turns, #13 AWG, 0.25" L, 0.5" Diameter (Position 1/4" from L2)

FIGURE 2 – 500 MHz OSCILLATOR CIRCUIT




Note 1 – Coaxial-Line output network consisting of:
2 General Radio Type 874-TEE or equivalent
1 General Radio Type 874-D20 Adjustable Stub or equivalent
1 General Radio Type 874-LA Adjustable Line or equivalent
1 General Radio Type 874-WN3 Short-circuit termination or equivalent

Note 2 – RFC = 0.2 μH Ohmite #2-460 or equivalent

Note 3 – Lead Number 4 (case) floating

L1 – 2 turns #16 AWG wire, 3/8 inch OD, 1-1/4 inch long

Q = 2N5179

FIGURE 3 – NOISE FIGURE versus FREQUENCY

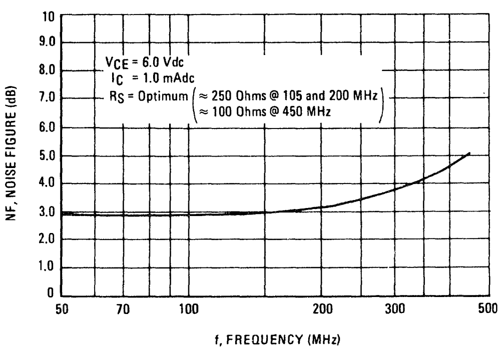



FIGURE 4 – NOISE FIGURE versus SOURCE RESISTANCE and COLLECTOR CURRENT

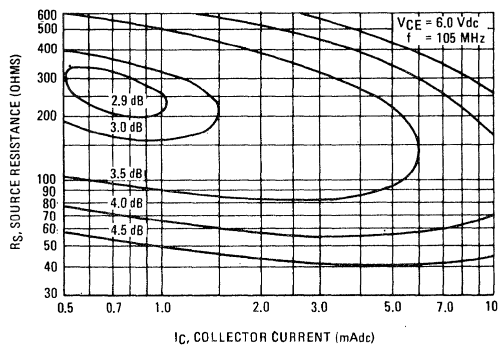



FIGURE 5 – NOISE FIGURE versus SOURCE RESISTANCE and COLLECTOR CURRENT

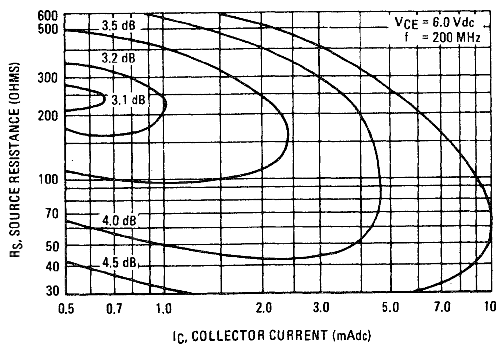


FIGURE 6 — CURRENT-GAIN-BANDWIDTH PRODUCT

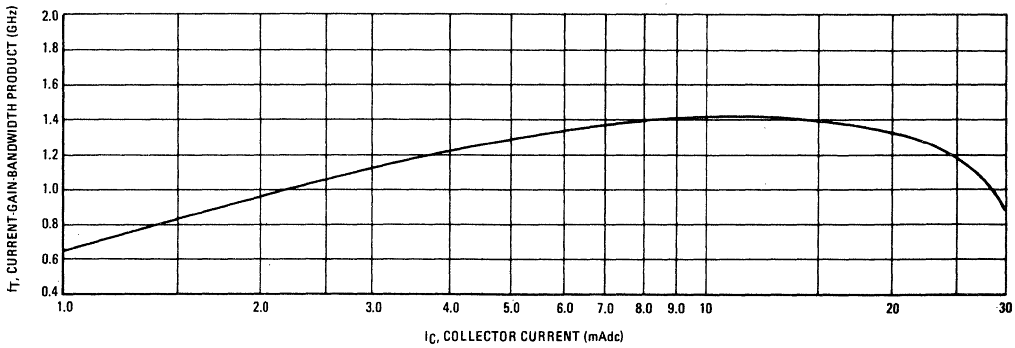



FIGURE 7 — INPUT ADMITTANCE versus FREQUENCY

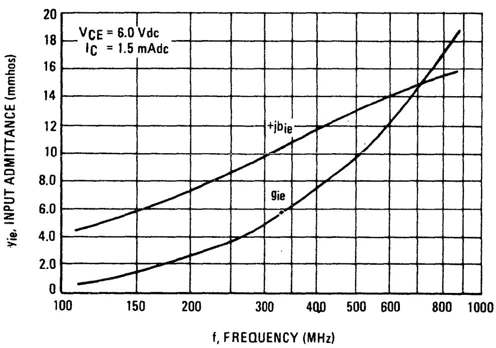



FIGURE 8 — OUTPUT ADMITTANCE versus FREQUENCY

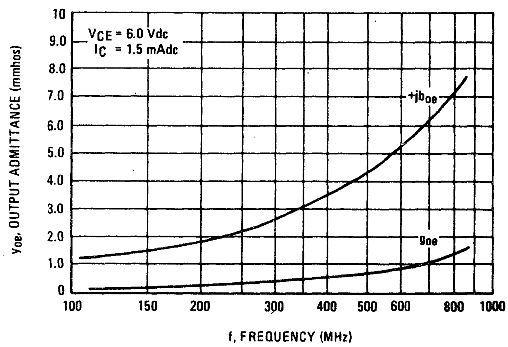



FIGURE 9 — FORWARD TRANSFER ADMITTANCE versus FREQUENCY

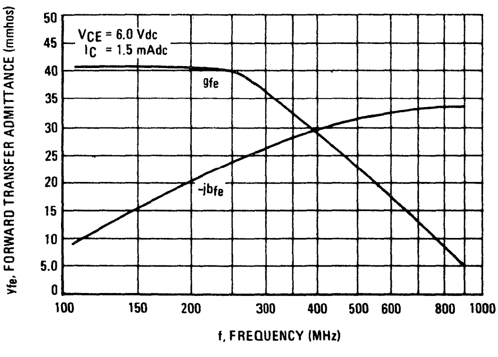



FIGURE 10 — REVERSE TRANSFER ADMITTANCE versus FREQUENCY

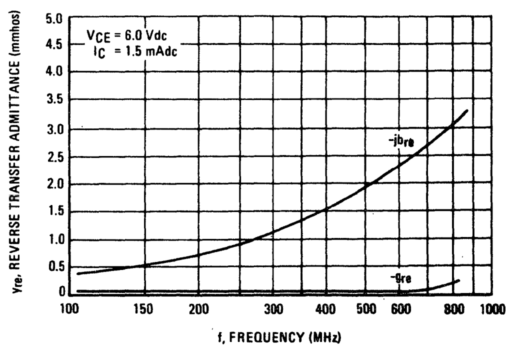


FIGURE 11 – $S_{11}$, INPUT REFLECTION COEFFICIENT

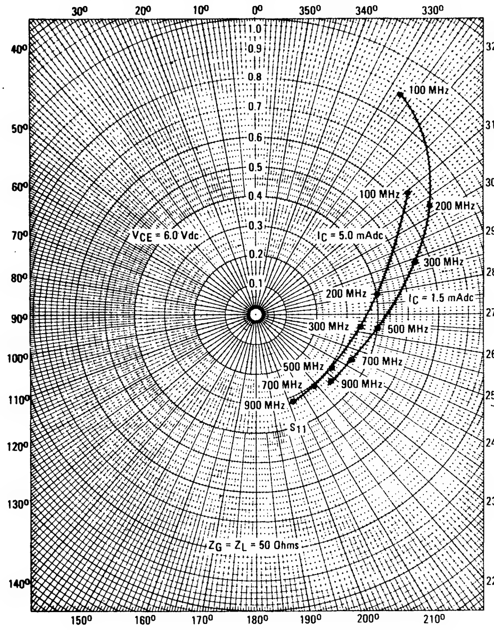



FIGURE 12 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

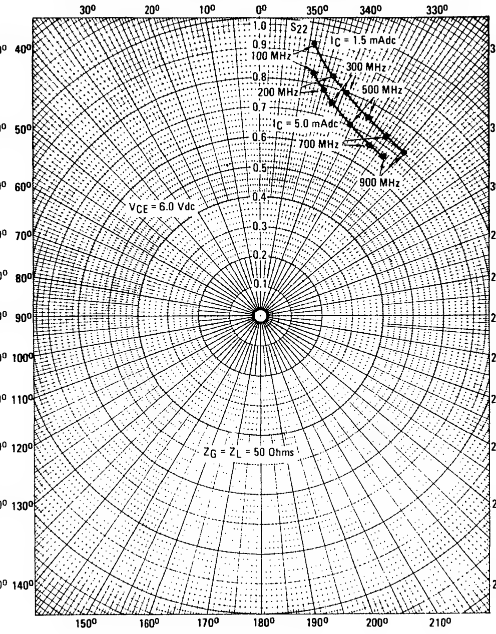



FIGURE 13 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

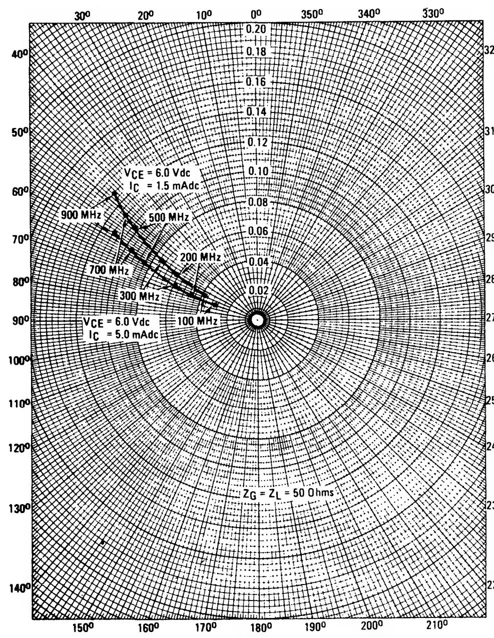



FIGURE 14 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT

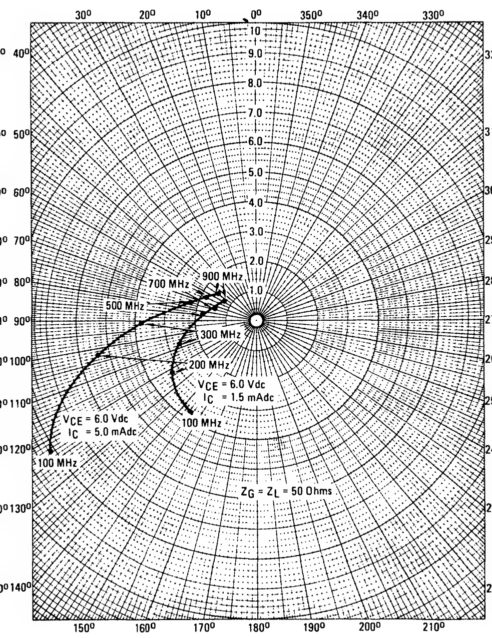
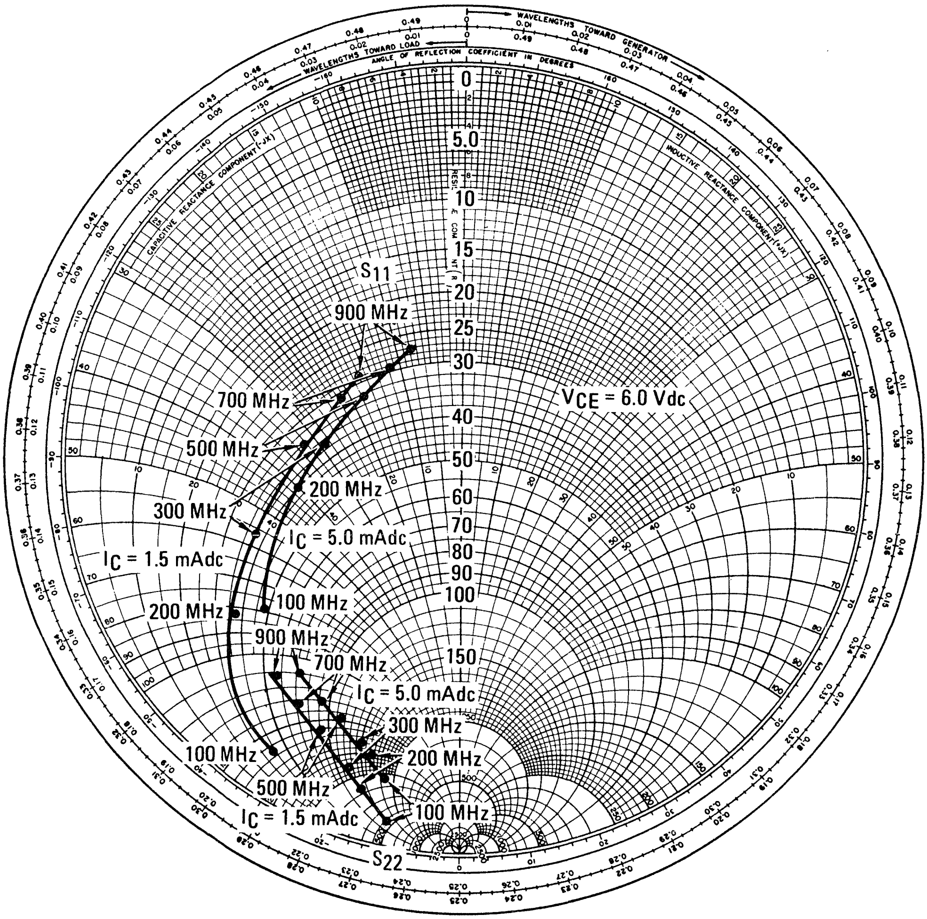


FIGURE 15 — $S_{11}$, INPUT REFLECTION COEFFICIENT AND $S_{22}$, OUTPUT REFLECTION COEFFICIENT



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5583

## The RF Line

### PNP SILICON HIGH-FREQUENCY TRANSISTOR

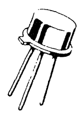
. . . designed for applications in high frequency amplifiers and non-saturated switching circuits. High gain-bandwidth product characteristic provides excellent performance in a variety of small signal and linear amplifier applications.

- High Current-Gain—Bandwidth Product — $f_T$ = 1300 (Min) @ $I_C$ = 100 mAdc
- Low Collector-Base Time Constant — $r_b'C_c$ = 8.0 ps (Typ) @ $I_C$ = 50 mAdc

**1.3 GHz @ 100 mAdc**

**HIGH-FREQUENCY TRANSISTOR**

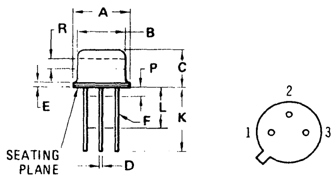
**PNP SILICON**

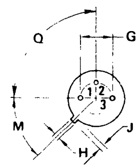


### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| *Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| *Collector-Base Voltage | $V_{CB}$ | 30 | Vdc |
| *Emitter-Base Voltage | $V_{EB}$ | 3.0 | Vdc |
| *Collector Current — Continuous | $I_C$ | 500 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 1.0<br>5.71 | Watt<br>mW/°C |
| *Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| *Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.




STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEBEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Figure No. | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| ***OFF CHARACTERISTICS** | | | | | | |
| Collector-Emitter Breakdown Voltage (Note 1) ($I_C$ = 10 mAdc, $I_B$ = 0) | – | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 10 μAdc, $I_E$ = 0) | – | $BV_{CBO}$ | 30 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | – | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 20 Vdc, $I_E$ = 0) | 4 | $I_{CBO}$ | – | – | 50 | nAdc |
| Emitter Cutoff Current ($V_{EB}$ = 2.0 Vdc, $I_C$ = 0) | – | $I_{EBO}$ | – | – | 0.5 | μAdc |
| ***ON CHARACTERISTICS** | | | | | | |
| DC Current Gain (Note 1) | 1 | $h_{FE}$ | | | | – |
| ($I_C$ = 40 mAdc, $V_{CE}$ = 2.0 Vdc) | | | 20 | 40 | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 2.0 Vdc) | | | 25 | 40 | 100 | |
| ($I_C$ = 300 mAdc, $V_{CE}$ = 5.0 Vdc) | | | 15 | 22 | – | |
| Collector-Emitter Saturation Voltage (Note 1) ($I_C$ = 100 mAdc, $I_B$ = 10 mAdc) | 2,3 | $V_{CE(sat)}$ | – | 0.6 | 0.8 | Vdc |
| Base-Emitter On Voltage (Note 1) ($I_C$ = 100 mAdc, $V_{CE}$ = 2.0 Vdc) | 3 | $V_{BE(on)}$ | – | 0.84 | 1.8 | Vdc |
| **SMALL-SIGNAL CHARACTERISTICS** | | | | | | |
| *Current-Gain—Bandwidth Product | 7 | $f_T$ | | | | MHz |
| ($I_C$ = 40 mAdc, $V_{CE}$ = 10 Vdc, f = 100 MHz) | | | 1000 | 1300 | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc, f = 100 MHz) | | | 1300 | 1500 | – | |
| *Collector-Base Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 100 kHz) | 5 | $C_{cb}$ | – | 2.5 | 5.0 | pF |
| *Emitter-Base Capacitance ($V_{EB}$ = 0.5 Vdc, $I_C$ = 0, f = 100 kHz) | 5 | $C_{eb}$ | – | 18 | 35 | pF |
| Collector-Base Time Constant ($I_C$ = 50 mAdc, $V_{CB}$ = 10 Vdc, f = 63.6 MHz) | 8 | $r_b'C_c$ | – | ~ 8.0 | – | ps |
| **SWITCHING CHARACTERISTICS** | | | | | | |
| Delay Time ($V_{CC}$ = 31.4 Vdc, $I_C$ = 150 mAdc, $R_C$ = 160 Ohms, $R_E$ = 26.6 Ohms) | 9,10 | $t_d$ | – | 1.0 | – | ns |
| Rise Time | 9,10 | $t_r$ | – | 2.1 | – | ns |
| Fall Time | 9,10 | $t_f$ | – | 1.8 | – | ns |

*Indicates JEDEC Registered Data.
Note 1: Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle = 2.0%.

FIGURE 1 – DC CURRENT GAIN

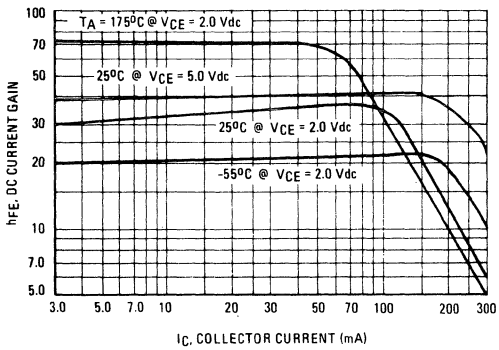



FIGURE 2 – COLLECTOR SATURATION REGION

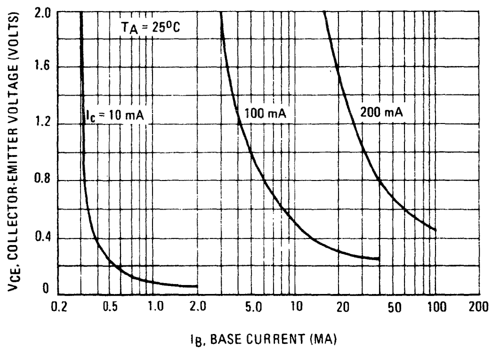



FIGURE 3 – "ON" VOLTAGES

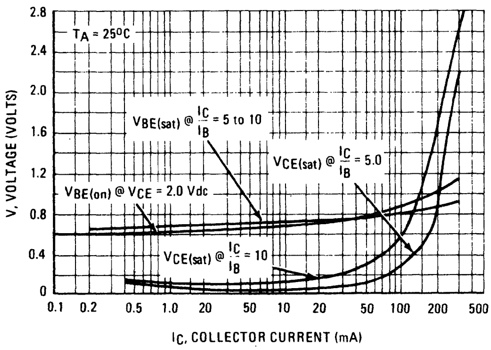



FIGURE 4 – COLLECTOR CURRENT versus BASE VOLTAGE

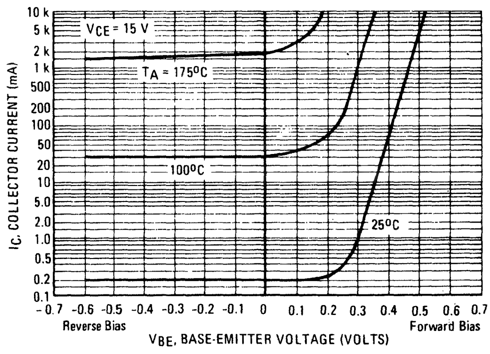



FIGURE 5 – CAPACITANCES

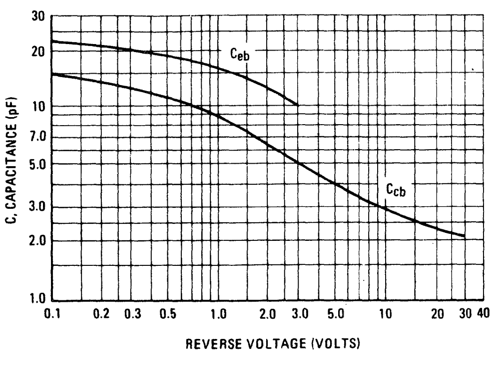



FIGURE 6 – TEMPERATURE COEFFICIENTS

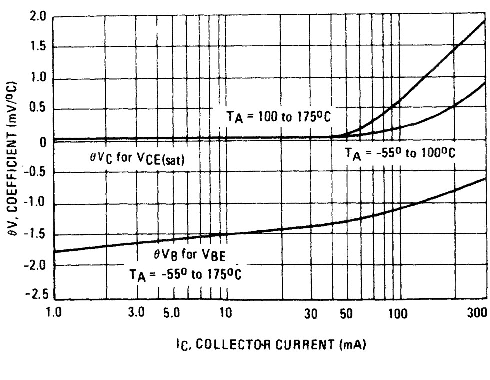



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FIGURE 7 – CURRENT-GAIN–BANDWIDTH PRODUCT

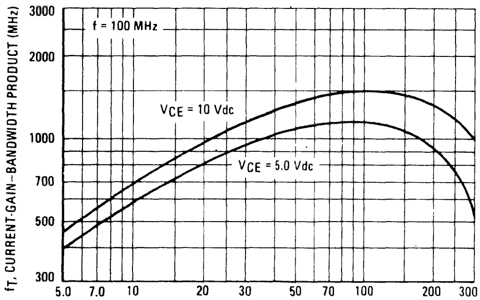



FIGURE 8 – COLLECTOR-BASE TIME CONSTANT

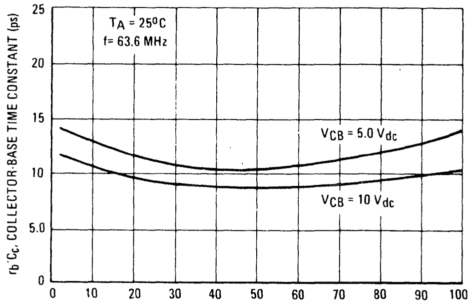



FIGURE 9 – SWITCHING TIMES

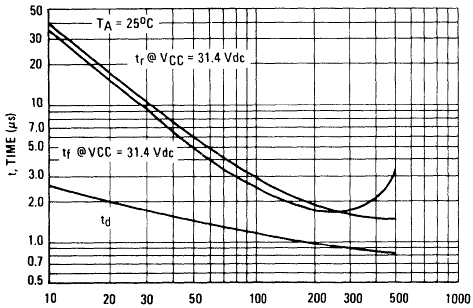
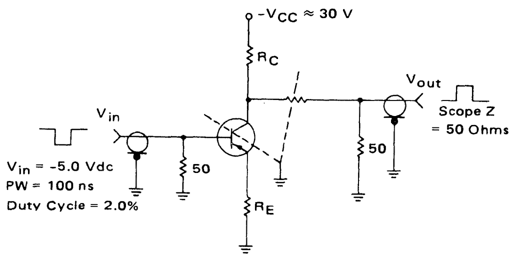



FIGURE 10 – SWITCHING TIMES TEST CIRCUIT




| $I_C$ mA | $R_C$ Ohms | $R_E$ Ohms | $V_{CC}$ Volts |
|---|---|---|---|
| 50 | 526 | 80 | 34.4 |
| 150 | 160 | 26.6 | 31.4 |
| 300 | 78 | 13.3 | 30.6 |
| 500 | 46.5 | 8.0 | 30.3 |

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# 2N5835
# 2N5836
# 2N5837

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTORS

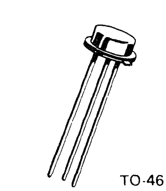
. . . designed primarily for use in fact current-mode switching circuits in military and industrial equipment. Suitable for use in general high-frequency amplifier applications to 1.5 GHz.

- 2N5835 – 10 mAdc, 6.0 Vdc Characteristics
  - $f_T$ = 2.5 GHz (Min)
  - $r_b'C_c$ = 5.0 ps (Typ)
  - $t_r$ = 250 ps (Typ)
- 2N5836 – 50 mAdc, 6.0 Vdc Characteristics –
  - $f_T$ = 2.0 GHz (Min)
  - $r_b'C_c$ = 6.0 ps (Typ)
  - $t_r$ = 320 ps (Typ)
- 2N5837 – 100 mAdc, 3.0 Vdc Characteristics –
  - $f_T$ = 1.7 GHz (Min)
  - $r_b'C_c$ = 6.0 ps (Typ)
  - $t_r$ = 650 ps (Typ)

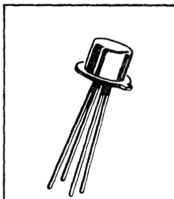
2.5 GHz @ 10 mAdc – 2N5835
2.0 GHz @ 50 mAdc – 2N5836
1.7 GHz @ 100 mAdc – 2N5837

**HIGH FREQUENCY TRANSISTORS**

**NPN SILICON**



TO-46
2N5836
2N5837

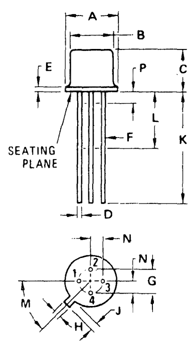


TO-72
2N5835

### *MAXIMUM RATINGS

| Rating | Symbol | 2N5835 | 2N5836 | 2N5837 | Unit |
|---|---|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 10 | 10 | 5.0 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 15 | 15 | 10 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | 3.5 | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 15 | 200 | 300 | mAdc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 200<br>1.14 | –<br>– | –<br>– | mW<br>mW/$^oC$ |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | –<br>– | 2.0<br>11.43 | 2.0<br>11.43 | Watts<br>mW/$^oC$ |
| Storage Junction Temperature Range | $T_{stg}$ | ← -65 to +200 → | | | $^oC$ |

*Indicates JEDEC Registered Data.



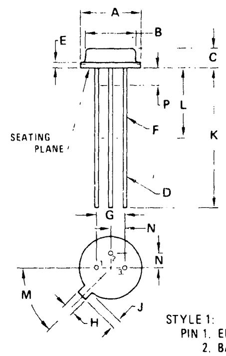


STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0 170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2 54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45°BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | - | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

CASE 20-03
TO-72





STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 1.65 | 2.16 | 0.065 | 0.085 |
| D | 0.406 | 0.533 | 0 016 | 0.021 |
| E | – | 1.02 | | 0.040 |
| F | 0.305 | 0.483 | 0.012 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.914 | 1.17 | 0.036 | 0.046 |
| J | 0.711 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

All JEDEC dimensions and notes apply

CASE 26-03
TO-46

*ELECTRICAL CHARACTERISTICS ($T_A$ = 25°C unless otherwise noted)

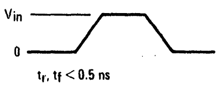
| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | |
| Collector-Base Breakdown Voltage | | $BV_{CBO}$ | | | | Vdc |
| ($I_C$ = 10 μAdc, $I_E$ = 0) | 2N5835 | | 15 | – | – | |
| ($I_C$ = 100 μAdc, $I_E$ = 0) | 2N5836 | | 15 | – | – | |
| | 2N5837 | | 10 | – | – | |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current | | $I_{CBO}$ | | | | μAdc |
| ($V_{CB}$ = 7.5 Vdc, $I_E$ = 0) | 2N5835 | | – | – | 0.01 | |
| ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | 2N5836 | | – | – | 10 | |
| ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0) | 2N5837 | | – | – | 10 | |
| Emitter Cutoff Current ($V_{EB}$ = 3.0 Vdc, $I_C$ = 0) | | $I_{EBO}$ | – | – | 100 | μAdc |
| **ON CHARACTERISTICS** | | | | | | |
| DC Current Gain | | $h_{FE}$ | | | | – |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 6.0 Vdc) | 2N5835 | | 25 | – | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 6.0 Vdc) | 2N5836 | | 25 | – | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 3.0 Vdc) | 2N5837 | | 25 | – | – | |
| Base-Emitter On Voltage | | $V_{BE(on)}$ | | | | Vdc |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 6.0 Vdc) | 2N5835 | | – | – | 0.9 | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 6.0 Vdc) | 2N5836 | | – | – | 0.9 | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 3.0 Vdc) | 2N5837 | | – | – | 0.9 | |
| **DYNAMIC CHARACTERISTICS** | | | | | | |
| Current-Gain—Bandwidth Product ① | | $f_T$ | | | | GHz |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 6.0 Vdc, f = 200 MHz) | 2N5835 | | 2.5 | – | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 6.0 Vdc, f = 200 MHz) | 2N5836 | | 2.0 | – | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 3.0 Vdc, f = 200 MHz) | 2N5837 | | 1.7 | – | – | |
| Collector-Base Capacitance | | $C_{cb}$ | | | | pF |
| ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | 2N5835 | | – | – | 0.8 | |
| | 2N5836 | | – | – | 3.5 | |
| ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0, f = 0.1 to 1.0 MHz) | 2N5837 | | – | – | 5.0 | |
| Collector-Base Time Constant ② | | $r_b'C_c$ | | | | ps |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 6.0 Vdc, f = 63.6 MHz) | 2N5835 | | – | 5.0 | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 6.0 Vdc, f = 63.6 MHz) | 2N5836 | | – | 6.0 | – | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 3.0 Vdc, f = 63.6 MHz) | 2N5837 | | – | 6.0 | – | |
| **SWITCHING CHARACTERISTICS ②** | | | | | | |
| Rise Time (See Figure 1) ($I_C$ = 10 mAdc) | 2N5835 | $t_r$ | – | 250 | – | ps |
| ($I_C$ = 40 mAdc) | 2N5836 | | – | 320 | – | |
| ($I_C$ = 100 mAdc) | 2N5837 | | – | 650 | – | |

*Indicates JEDEC Registered Data

① $f_T$ is defined as the frequency at which $|h_{fe}|$ extrapolates to unity.

② Typical values shown in addition to JEDEC Registered Data.

**FIGURE 1 – SWITCHING TIME TEST CIRCUIT**




| $I_C$ mA | $R_E$ Ohms | $R_L$ Ohms | $R_K$ Ohms |
|---|---|---|---|
| 10 | 380 | 100 | 50 |
| 40 | 95 | 25 | 0 |
| 100 | 38 | 10 | 0 |
| 200 | 19 | 5.0 | 0 |

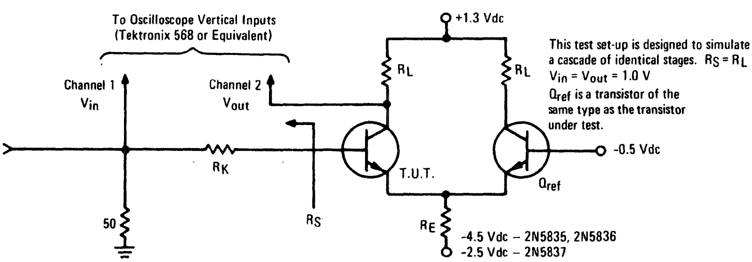


FIGURE 2 – SWITCHING TIME

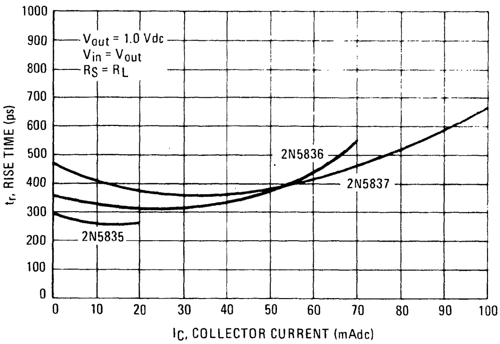



FIGURE 3 – CURRENT-GAIN–BANDWIDTH PRODUCT

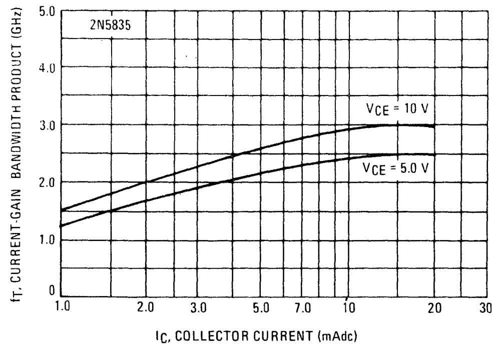



FIGURE 4 – CURRENT-GAIN–BANDWIDTH PRODUCT

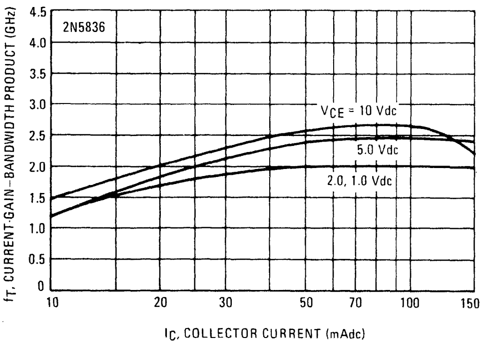



FIGURE 5 – CURRENT-GAIN–BANDWIDTH PRODUCT

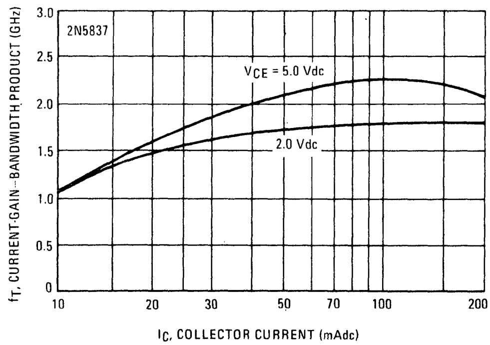



FIGURE 6 – COLLECTOR-BASE TIME CONSTANT

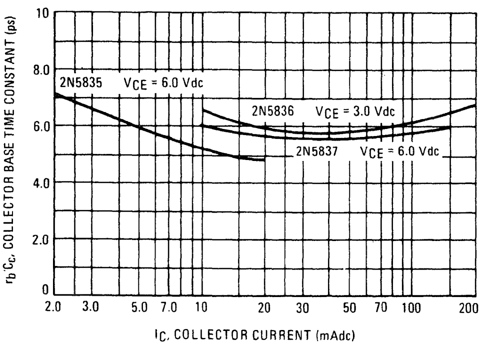
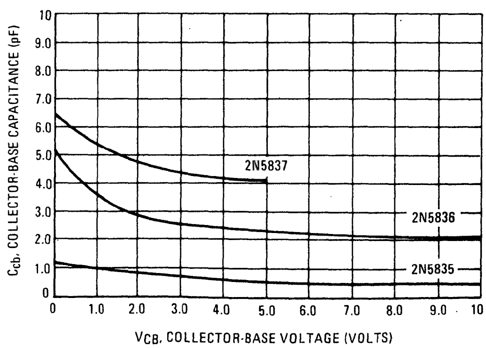



FIGURE 7 – COLLECTOR-BASE CAPACITANCE



## 2N5835 SCATTERING PARAMETERS
($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, $Z_G$ = $Z_L$ = 50 Ohms)

FIGURE 8 – $S_{11}$, INPUT REFLECTION COEFFICIENT

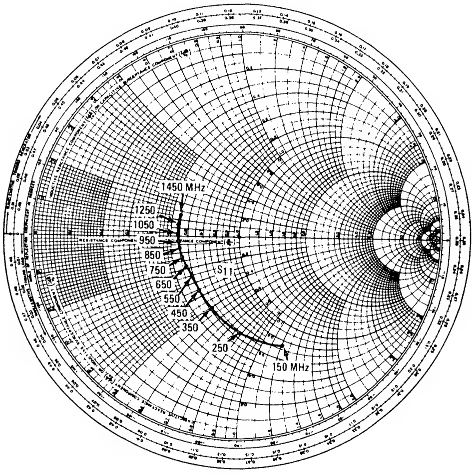



FIGURE 9 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

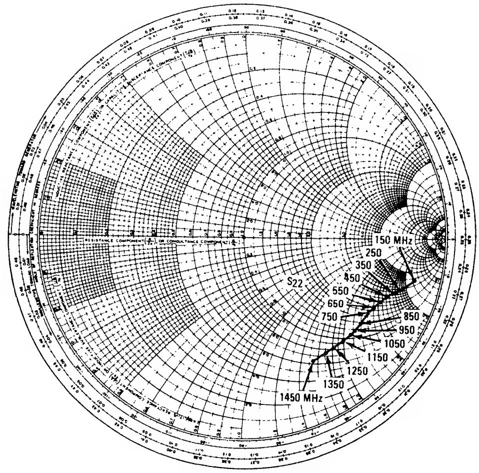



FIGURE 10 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

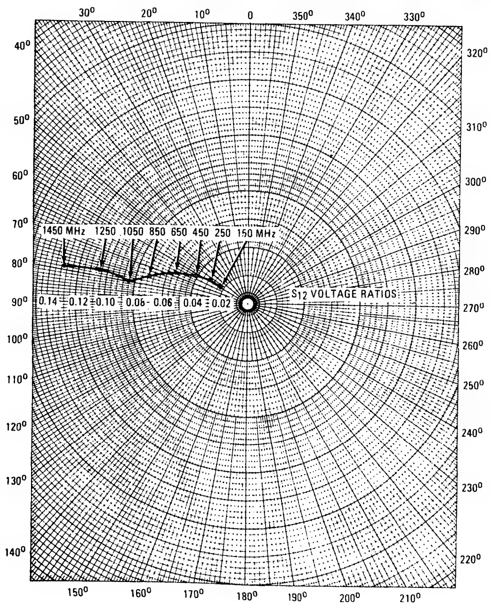
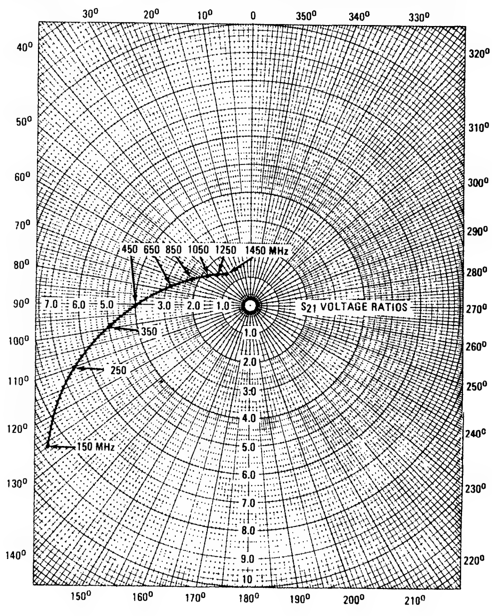



FIGURE 11 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT



## 2N5836 SCATTERING PARAMETERS

($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc, $Z_G$ = $Z_L$ = 50 Ohms)

FIGURE 12 – $S_{11}$, INPUT REFLECTION COEFFICIENT

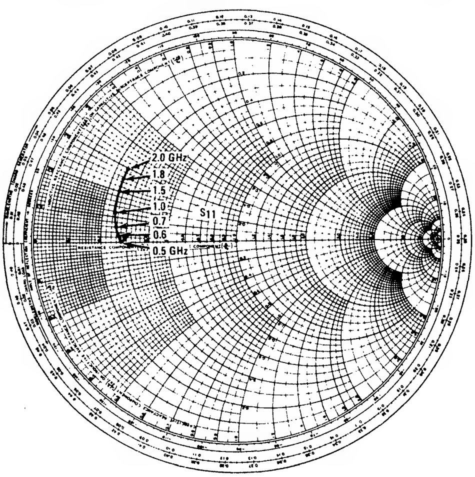



FIGURE 13 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

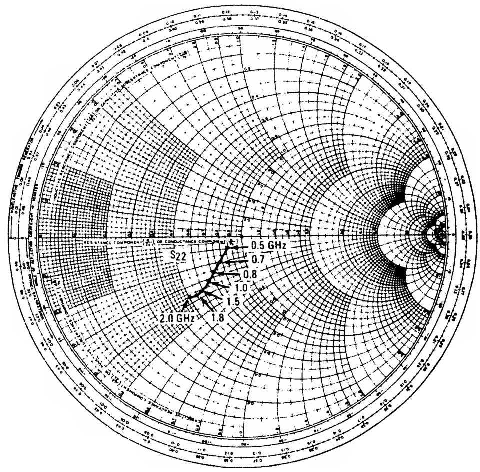



FIGURE 14 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

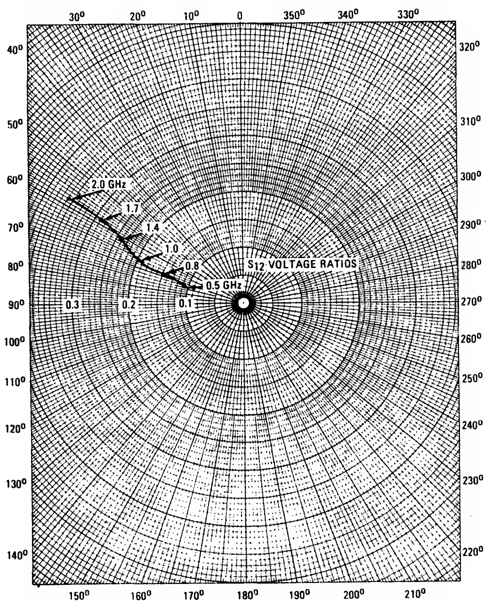
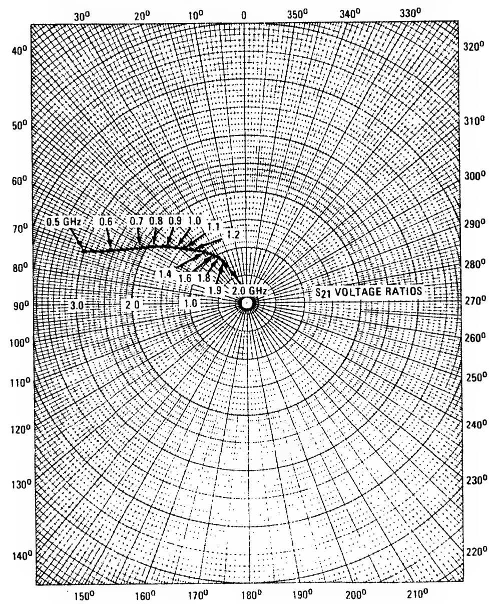



FIGURE 15 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT



## 2N5837 SCATTERING PARAMETERS
($I_C$ = 100 mAdc, $V_{CE}$ = 3.0 Vdc, $Z_G$ = $Z_L$ = 50 Ohms)

FIGURE 16 – $S_{11}$, INPUT REFLECTION COEFFICIENT

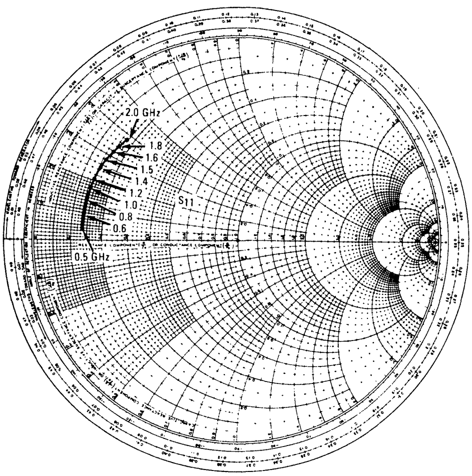



FIGURE 17 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

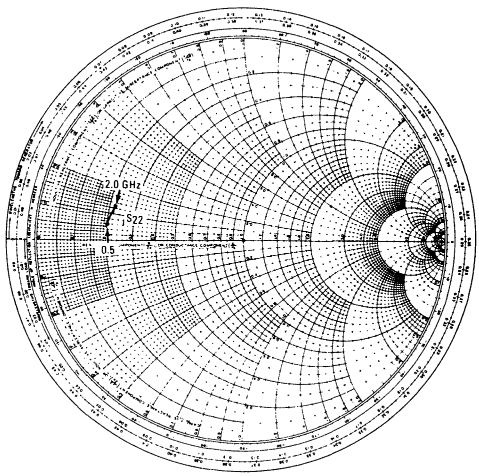



FIGURE 18 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

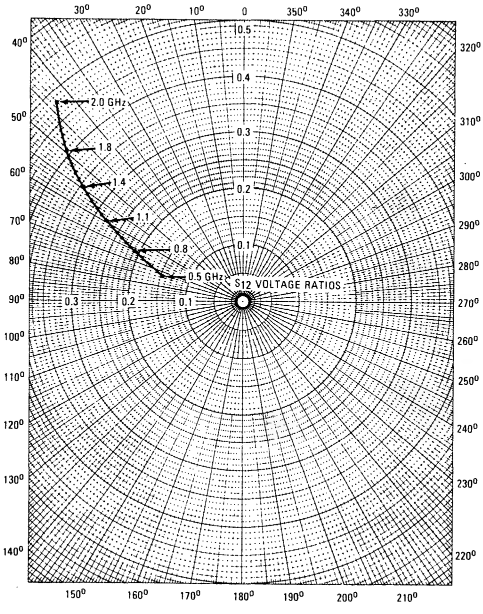
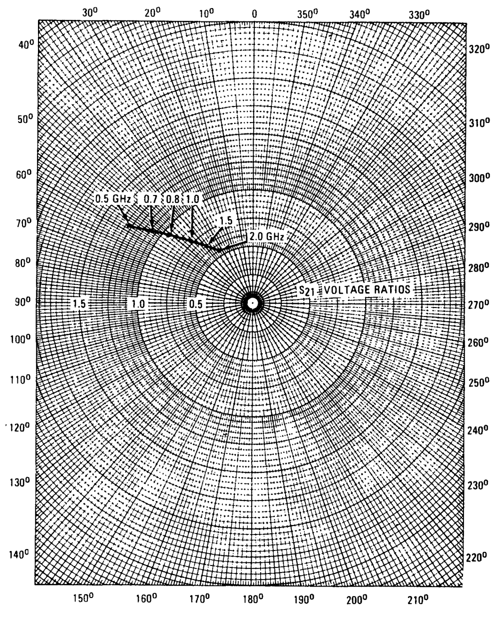



FIGURE 19 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N5841
# 2N5842

## The RF Line

2.2 GHz @ 25 mA – 2N5841
1.7 GHz @ 25 mA – 2N5842

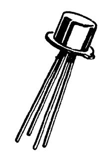
HIGH-FREQUENCY TRANSISTORS

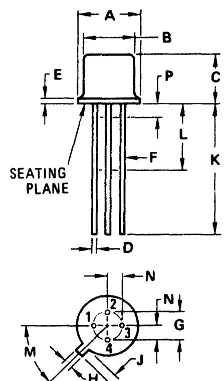
NPN SILICON

### NPN SILICON HIGH-FREQUENCY TRANSISTORS

. . . designed to provide ultra-fast switching times in current-mode circuits at collector currents to 80 mAdc.

- High Current-Gain–Bandwidth Product – @ $I_C$ = 25 mAdc
  $f_T$ = 2.2 GHz (Min) 2N5841
  1.7 GHz (Min) 2N5842
- Low Collector-Base Capacitance –
  $C_{cb}$ = 1.5 pF (Max) @ $V_{CB}$ = 4.0 Vdc
- Fast Non-Saturated Switching Times – @ $I_C$ = 30 mAdc
  Typical Values
  $t_{d(on)}$ = 0.4 ns
  $t_r$ = 0.18 ns
  $t_{d(off)}$ = 0.3 ns
  $t_f$ = 0.20 ns






STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

CASE 20-03
TO-72

### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 10 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 100 | mAdc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 350<br>2.0 | mW<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J$, $T_{stg}$ | -65 to +200 | °C |

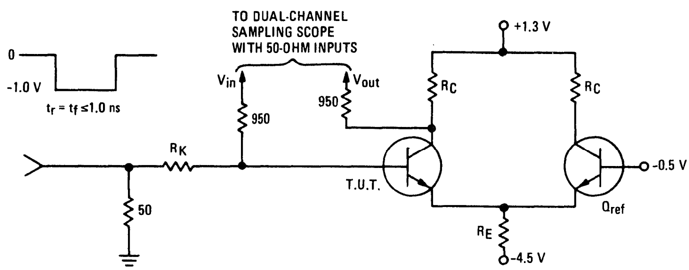
*Indicates JEDEC Registered Data.

*ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | | $V_{CEO(sus)}$ | 10 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | | $BV_{CBO}$ | 20 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | | $I_{CBO}$ | – | – | 20 | nAdc |
| Emitter Cutoff Current ($V_{BE}$ = 2.5 Vdc, $I_C$ = 0) | | $I_{EBO}$ | – | – | 100 | μAdc |
| **ON CHARACTERISTICS** | | | | | | |
| DC Current Gain ($I_C$ = 25 mAdc, $V_{CE}$ = 4.0 Vdc) | 2N5841 | $h_{FE}$ | 25 | – | 200 | – |
| | 2N5842 | | 25 | – | 250 | |
| Base-Emitter On Voltage ($I_C$ = 25 mAdc, $V_{CE}$ = 4.0 Vdc) | | $V_{BE(on)}$ | – | – | 1.5 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 10 mAdc, $V_{CE}$ = 4.0 Vdc, f = 200 MHz) | 2N5841 | $f_T$ | 2.0 | 2.6 | – | GHz |
| | 2N5842 | | – | 2.0 | – | |
| ($I_C$ = 25 mAdc, $V_{CE}$ = 4.0 Vdc, f = 200 MHz) | 2N5841 | | 2.2 | 2.7 | – | |
| | 2N5842 | | 1.7 | 2.0 | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 4.0 Vdc, f = 200 MHz) | 2N5841 | | – | 2.2 | – | |
| | 2N5842 | | – | 1.5 | – | |
| Collector-Base Capacitance ($V_{CB}$ = 4.0 Vdc, $I_E$ = 0, f = 100 MHz) | | $C_{cb}$ | – | 0.9 | 1.5 | pF |
| Emitter-Base Capacitance ($V_{EB}$ = 0.5 Vdc, $I_C$ = 0, f = 100 MHz) | | $C_{eb}$ | – | 0.7 | 1.1 | pF |
| Collector-Base Time Constant ($I_C$ = 25 mAdc, $V_{CE}$ = 4.0 Vdc, f = 31.8 MHz) | 2N5841 | $r_b'C_c$ | – | 18 | 25 | ps |
| | 2N5842 | | – | 25 | 40 | |
| **SWITCHING CHARACTERISTICS** | | | | | | |
| Turn-On Delay Time | ($I_C$ = 30 mAdc) | $t_{d(on)}$ | – | 0.40 | – | ns |
| Rise Time | | $t_r$ | – | 0.18 | – | ns |
| Turn-Off Delay Time | ($I_C$ = 30 mAdc) | $t_{d(off)}$ | – | 0.30 | – | ns |
| Fall Time | | $t_f$ | – | 0.20 | – | ns |

*Indicates JEDEC Registered Data

FIGURE 1 – SWITCHING TIMES TEST CIRCUIT




| $I_C$ mA | $R_E$ Ohms | $R_C$ Ohms | $R_K$ Ohms |
|---|---|---|---|
| 1.0 | 3.8 k | 1.0 k | 950 |
| 2.0 | 1.9 k | 500 | 450 |
| 4.0 | 950 | 250 | 200 |
| 6.0 | 635 | 167 | 117 |
| 8.0 | 475 | 125 | 75 |
| 10 | 380 | 100 | 50 |
| 20 | 190 | 50 | 0 |
| 40 | 95 | 25 | 0 |
| 60 | 64 | 16-17 | 0 |
| 80 | 48 | 12-13 | 0 |
| 100 | 38 | 10 | 0 |

$V_{in}$ and $V_{out}$ are attenuated 20:1 at scope inputs. Before attenuation, $V_{in}$ = $V_{out}$ = 1.0 V.
$Q_{ref}$ is a transistor of the same type as the transistor under test.

FIGURE 2 – CURRENT GAIN BANDWIDTH PRODUCT

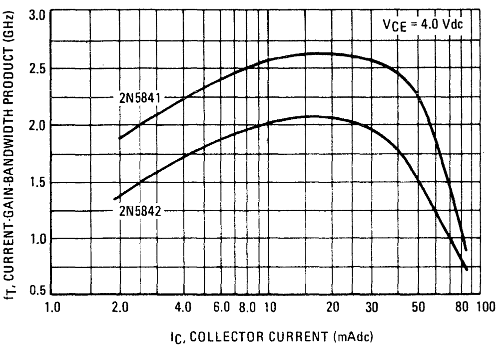



FIGURE 3 – COLLECTOR-BASE TIME CONSTANT

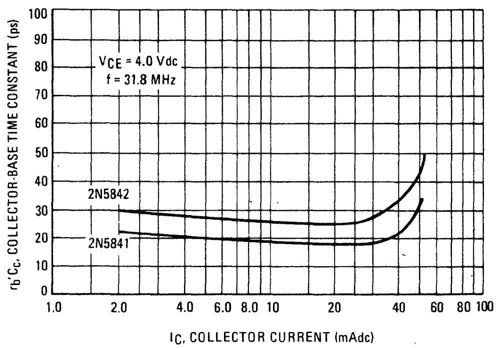



FIGURE 4 – SWITCHING TIMES

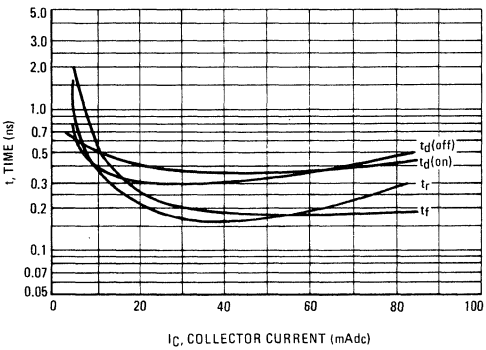



FIGURE 5 – CAPACITANCES

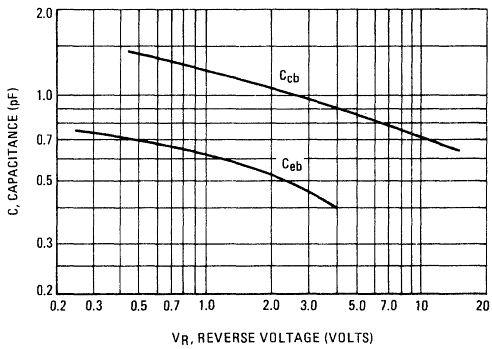



FIGURE 6 – BASE-EMITTER VOLTAGE versus CURRENT

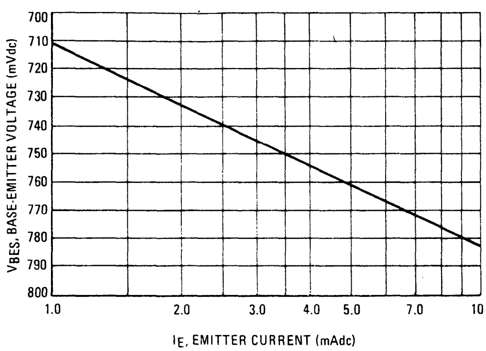
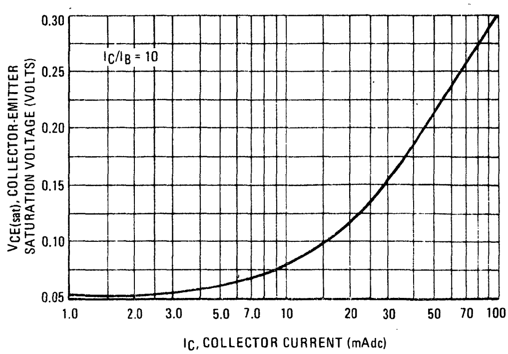



FIGURE 7 – COLLECTOR-EMITTER SATURATION VOLTAGE



$V_{CE}$ = 4.0 Vdc, $I_C$ = 10 mAdc

FIGURE 8 – INPUT ADMITTANCE versus FREQUENCY

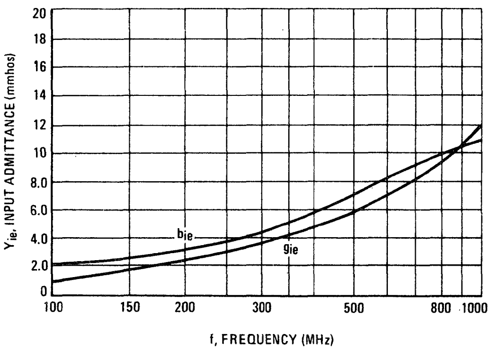



FIGURE 9 – OUTPUT ADMITTANCE versus FREQUENCY

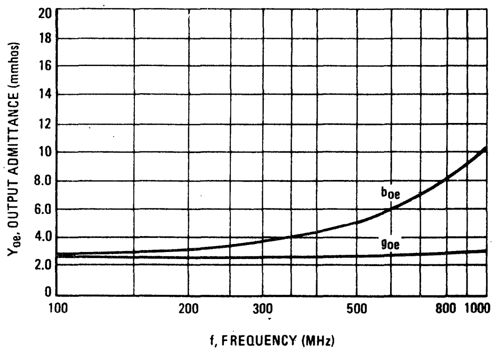



FIGURE 10 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

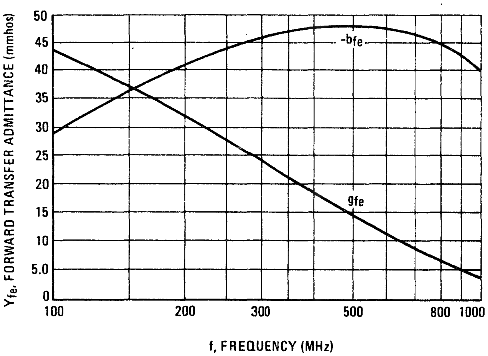
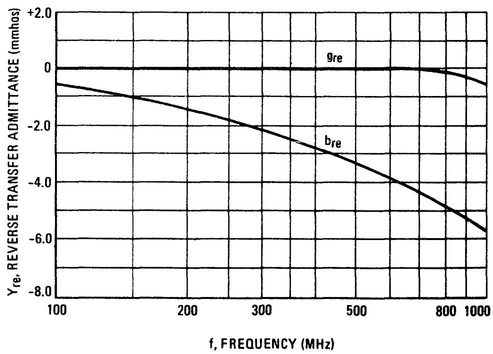
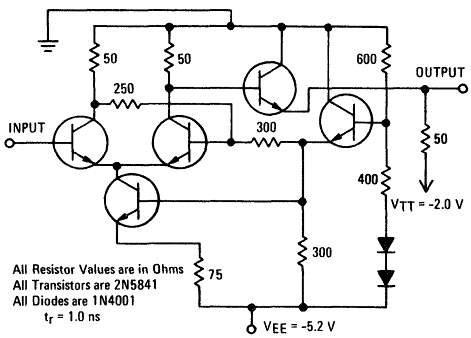



FIGURE 11 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY



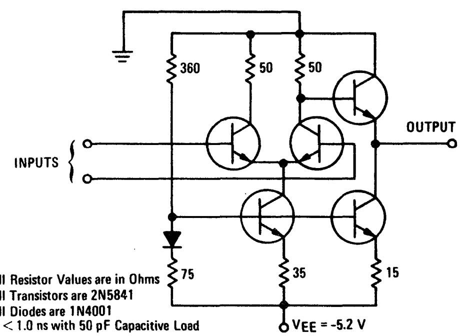

## NON-SATURATED SWITCHING APPLICATIONS

### SCHMITT TRIGGER




All Resistor Values are in Ohms
All Transistors are 2N5841
All Diodes are 1N4001
$t_r$ = 1.0 ns

### HIGH-SPEED CLOCK DRIVER




All Resistor Values are in Ohms
All Transistors are 2N5841
All Diodes are 1N4001
$t_r$ < 1.0 ns with 50 pF Capacitive Load

$V_{CE} = 4.0$ Vdc, $I_C = 10$ mAdc

FIGURE 12 – $S_{11}$, INPUT REFLECTION COEFFICIENT

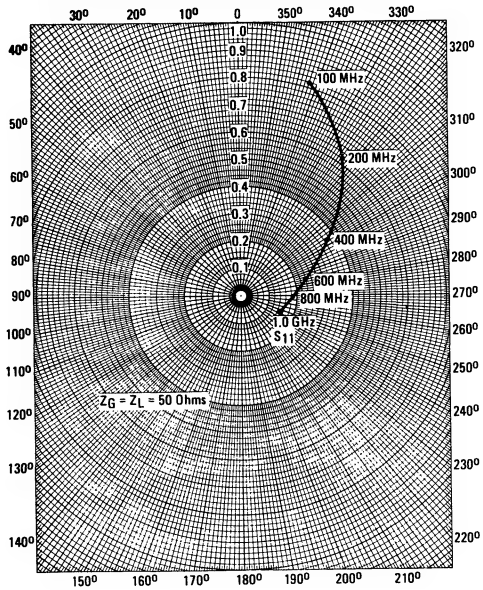



FIGURE 13 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

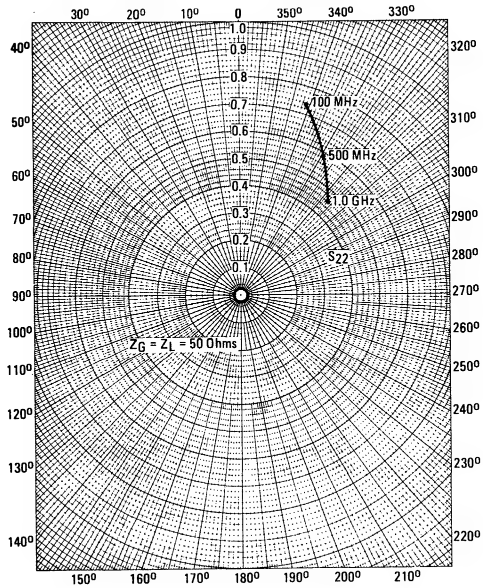



FIGURE 14 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT

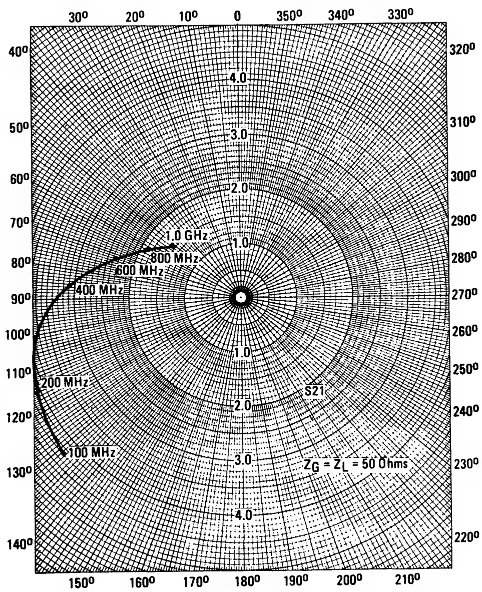
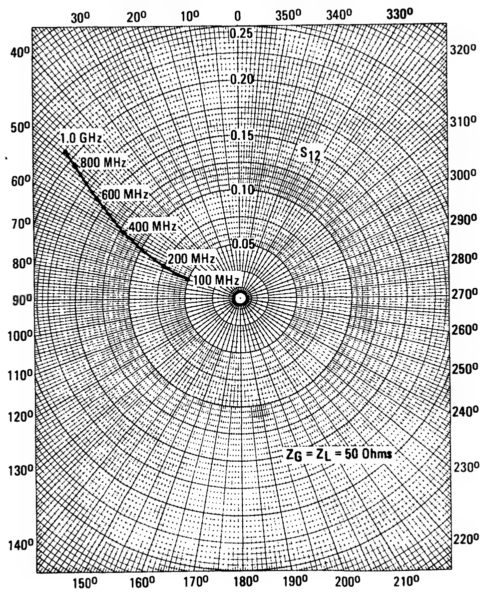



FIGURE 15 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT



$V_{CE}$ = 4.0 Vdc, $I_C$ = 10 mAdc

FIGURE 16 – $S_{11}$, INPUT REFLECTION COEFFICIENT

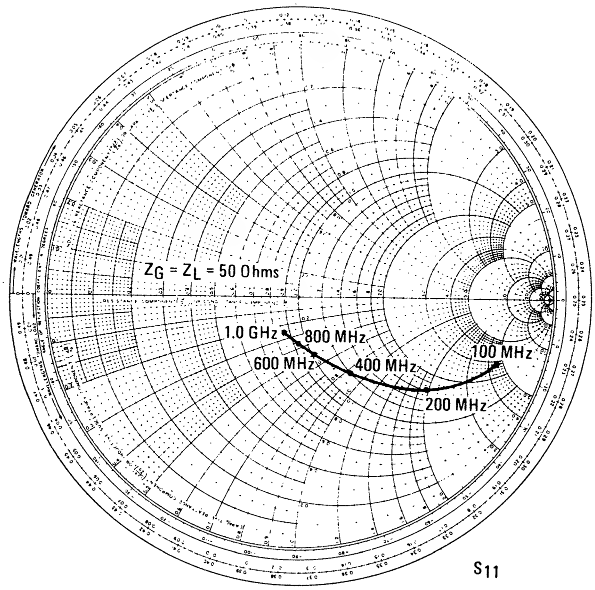
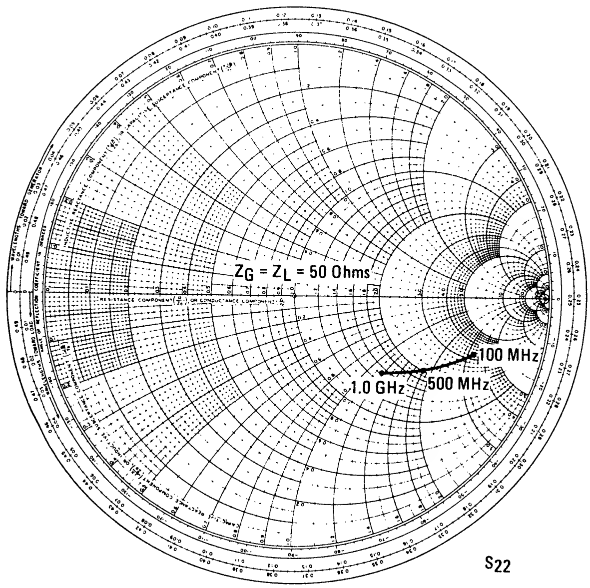



FIGURE 17 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT



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Semiconductors
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# 2N5943

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTOR

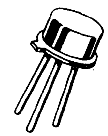
. . . designed specifically for broadband applications requiring low cross-modulation distortion and low-noise figure. Characterized for use in CATV applications.

- Low Noise Figure — @ f = 200 MHz
  NF (Narrowband) = 3.4 dB (Typ)
  NF (Broadband) = 6.8 dB (Typ)
- High Current-Gain — Bandwidth Product —
  $f_T$ = 1200 MHz (Min) @ $I_C$ = 50 mAdc
- Completely Characterized with s and y-Parameters

**1.2 GHz — 50 mAdc**

**NPN SILICON HIGH-FREQUENCY TRANSISTOR**

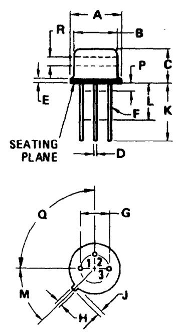
**NPN SILICON**



### *MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current — Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 1.0<br>5.7 | Watt<br>mW/$^oC$ |
| Total Device Dissipation @ $T_C = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 3.5<br>0.02 | Watts<br>W/$^oC$ |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | $^oC$ |

*Indicates JEDEC Registered Data.



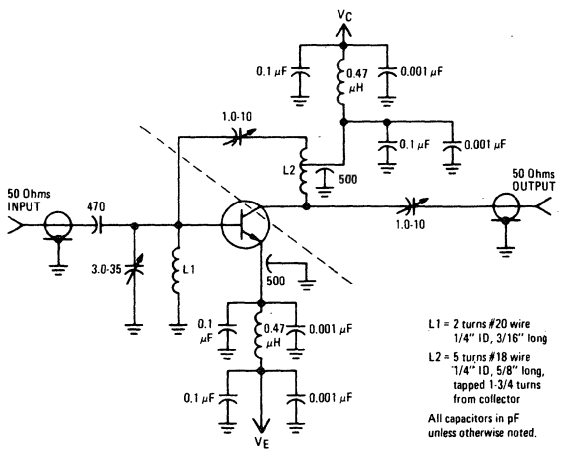

STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

#### FIGURE 1 — NARROW-BAND TEST CIRCUIT




L1 = 2 turns #20 wire
1/4" ID, 3/16" long
L2 = 5 turns #18 wire
1/4" ID, 5/8" long,
tapped 1-3/4 turns
from collector
All capacitors in pF
unless otherwise noted.

*ELECTRICAL CHARACTERISTICS ($T_A = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 20 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 50 | μAdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 10 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc) | $h_{FE}$ | 25 | – | 300 | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 10 mAdc) | $V_{CE(sat)}$ | – | 0.15 | 0.2 | Vdc |
| Base-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 10 mAdc) | $V_{BE(sat)}$ | – | 0.88 | 1.0 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain — Bandwidth Product (Figure 2) | $f_T$ | | | | MHz |
| ($I_C$ = 25 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | | 1000 | 1350 | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | | 1200 | 1550 | 2400 | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | | 1000 | 1425 | – | |
| Collector-Base Capacitance (Figure 5) ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 100 kHz) | $C_{cb}$ | 1.0 | 1.6 | 2.5 | pF |
| Emitter-Base Capacitance (Figure 5) ($V_{EB}$ = 0.5 Vdc, $I_C$ = 0, f = 100 kHz) | $C_{eb}$ | – | 8.4 | 15 | pF |
| Small-Signal Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 1.0 kHz) | $h_{fe}$ | 25 | – | 350 | – |
| Collector-Base Time Constant ($I_E$ = 50 mAdc, $V_{CB}$ = 15 Vdc, f = 31.8 MHz) | $r_b'C_c$ | 2.0 | 5.5 | 20 | ps |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) (Figure 1) | | – | 3.4 | – | |
| ($I_C$ = 35 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) (Figures 6, 11, 14) (1) | | – | 6.8 | 8.0 | |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain | $G_{pe}$ | | | | dB |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) (Figure 1) | | – | 11.4 | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 250 MHz) (Figure 6) | | 7.0 | 7.6 | – | |
| Intermodulation Distortion (Figure 7) ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, $V_{out}$ = +50 dBmV) | IM | – | – | -50 | dB |
| Cross Modulation Distortion (Figure 8) | XM | | | | dB |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, $V_{out}$ = +40 dBmV) | | – | -67 | – | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, $V_{out}$ = +50 dBmV) | | – | -45 | -42 | |

*Indicates JEDEC Registered Data.
(1) Includes noise figure of post-amplifier and matching pad.

**FIGURE 2 – CURRENT-GAIN – BANDWIDTH PRODUCT**

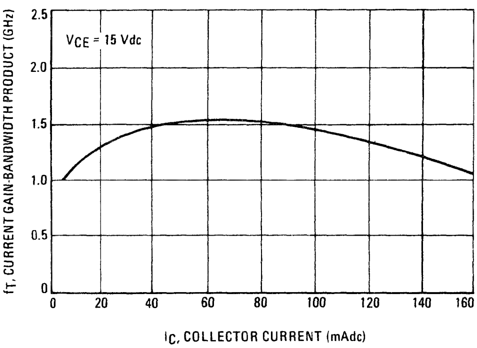



**FIGURE 3 – COLLECTOR-BASE TIME CONSTANT**

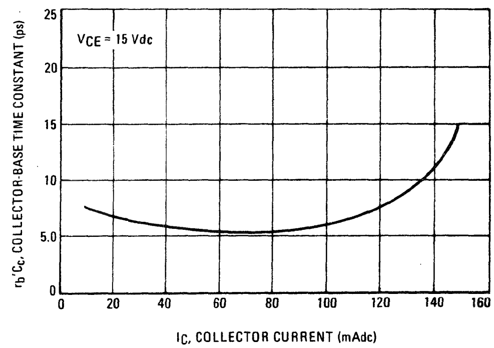



**FIGURE 4 – SATURATION VOLTAGES**

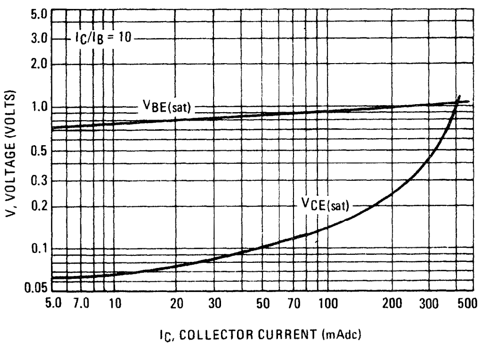



**FIGURE 5 – CAPACITANCES versus REVERSE VOLTAGE**

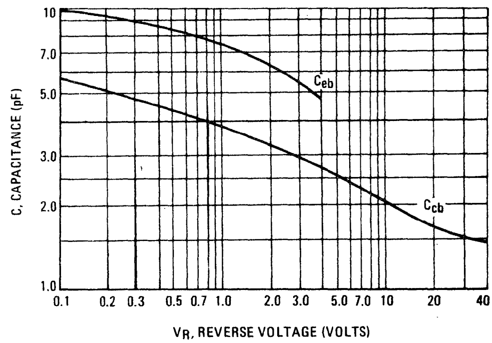
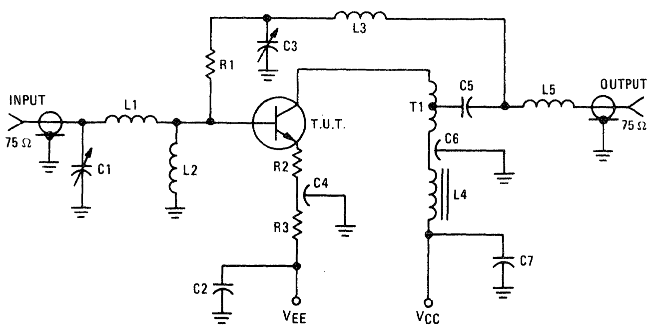



**FIGURE 6 – BROADBAND TEST CIRCUIT**




| | | |
|---|---|---|
| C1 | 1.0-10 pF | JOHANSON 2951 OR EQUIVALENT |
| C2, C7 | 0.01 μF | |
| C3 | 0.5-6.0 pF | JOHANSON 4642 OR EQUIVALENT |
| C4, C6 | 1500 pF | |
| C5 | 470 pF | |
| L1 | 2 TURNS AWG #26, 5/32" I.D. | |
| L2 | 1 μH MOLDED CHOKE | |
| L3 | 5 TURNS AWG #26, 3/32" I.D. | |
| L4 | FERRITE CHOKE, 3 TURNS #30 ON STACKPOLE 57-0156 BEAD | |
| L5 | 2 TURNS AWG #26, 3/32" I.D. | |
| T1 | AWG #30 TRIFILAR WOUND 1-9-9 ON STACKPOLE 57-0985, #11 TOROID | |
| R1 | 270 OHMS | |
| R2 | 18 OHMS | |
| R3 | 150 OHMS | |

GARLOCK TEFLON SOCKET

FIGURE 7 – CROSS-MODULATION DISTORTION versus COLLECTOR CURRENT

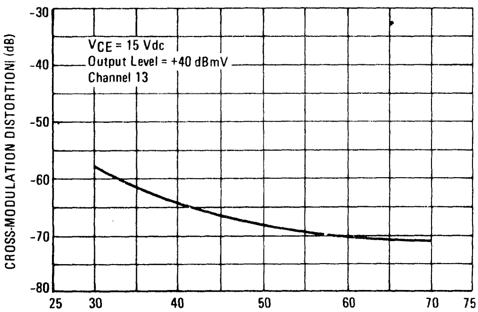



FIGURE 8 – CROSS-MODULATION DISTORTION versus OUTPUT LEVEL

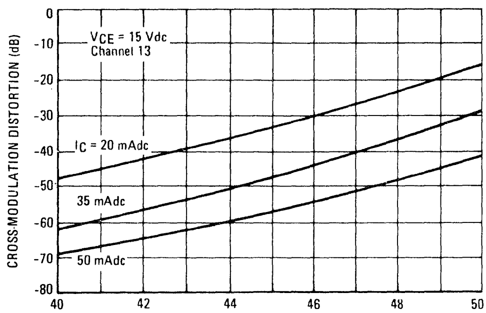



FIGURE 9 – NARROWBAND NOISE FIGURE versus COLLECTOR CURRENT

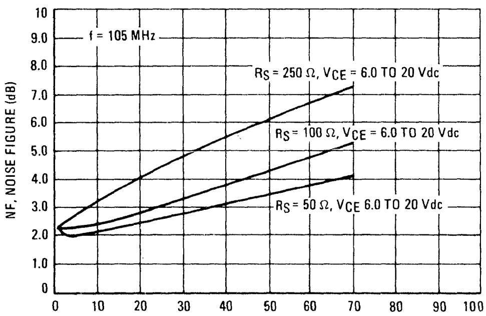



FIGURE 10 – NARROWBAND NOISE FIGURE versus COLLECTOR CURRENT

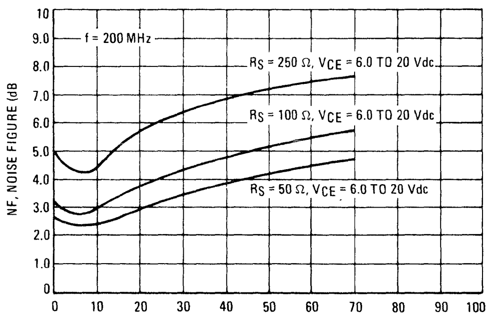



FIGURE 11 – BROADBAND NOISE FIGURE versus COLLECTOR CURRENT

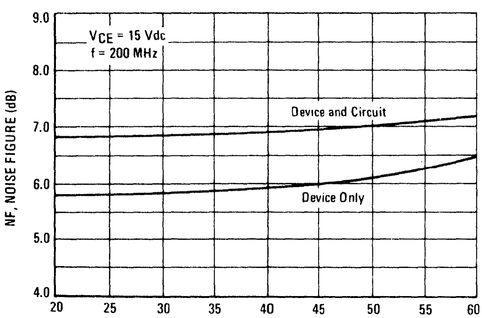



FIGURE 12 – NARROWBAND NOISE FIGURE versus FREQUENCY

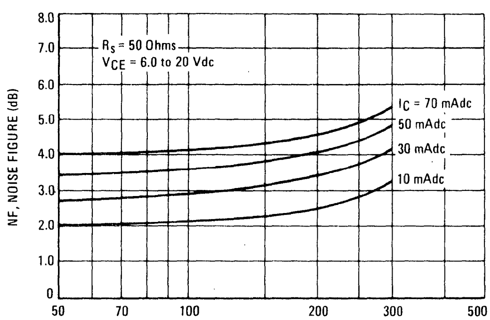


FIGURE 13 – INPUT ADMITTANCE versus FREQUENCY

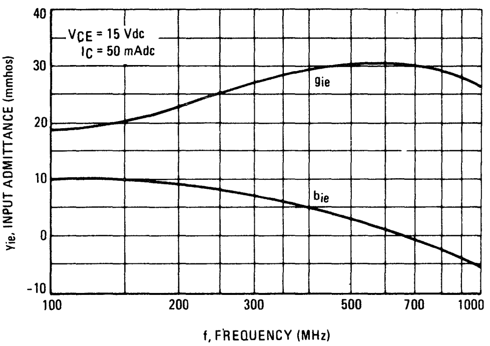



FIGURE 14 – INPUT ADMITTANCE versus COLLECTOR CURRENT

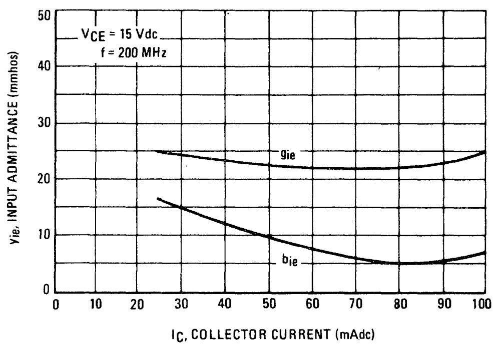



FIGURE 15 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY

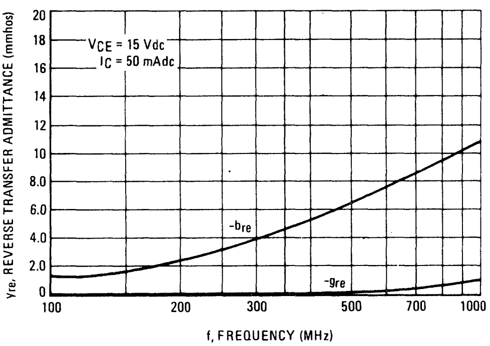



FIGURE 16 – REVERSE TRANSFER ADMITTANCE versus COLLECTOR CURRENT

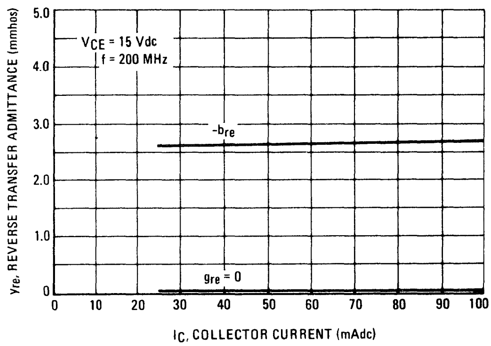



FIGURE 17 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

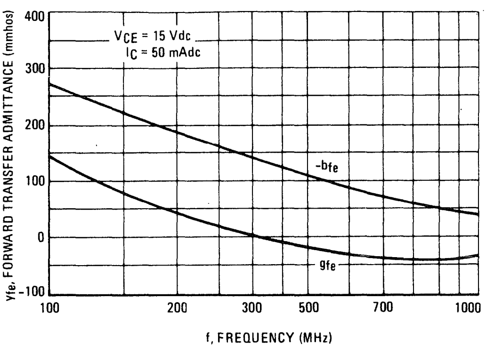



FIGURE 18 – FORWARD TRANSFER ADMITTANCE versus COLLECTOR CURRENT

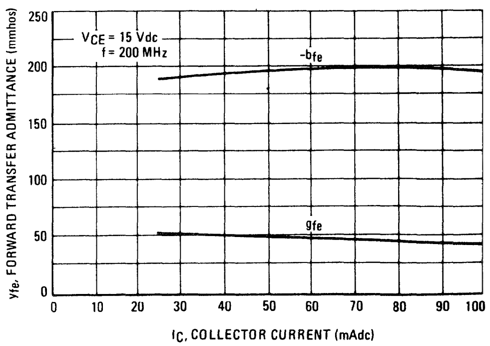


FIGURE 19 – OUTPUT ADMITTANCE versus FREQUENCY

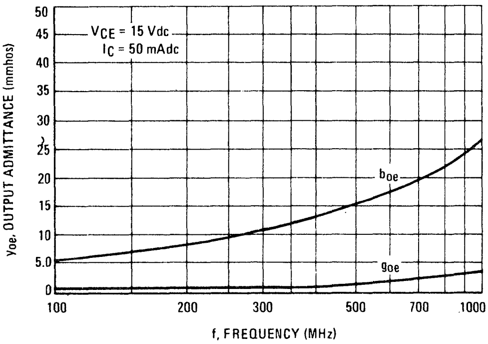



FIGURE 20 – OUTPUT ADMITTANCE versus COLLECTOR CURRENT

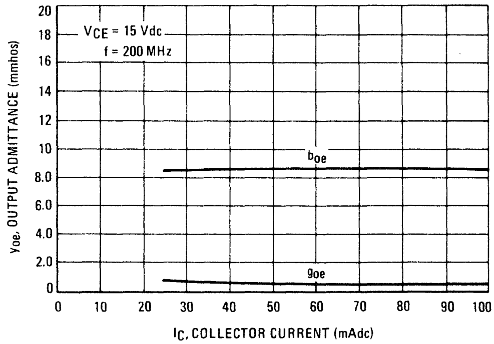



FIGURE 21 – INPUT REFLECTION COEFFICIENT versus FREQUENCY

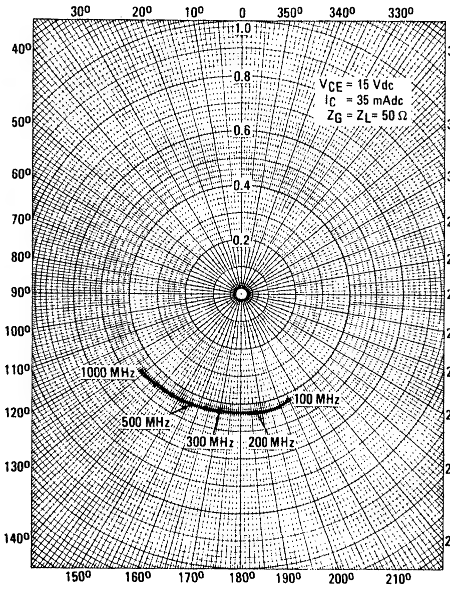



FIGURE 22 – OUTPUT REFLECTION COEFFICIENT versus FREQUENCY

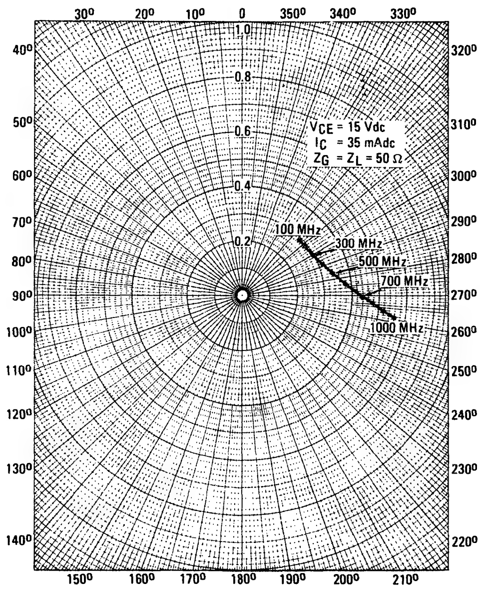


FIGURE 23 – REVERSE TRANSMISSION COEFFICIENT versus FREQUENCY

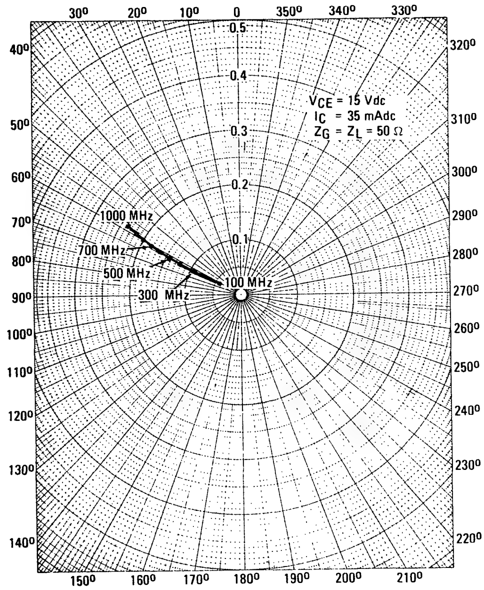



FIGURE 24 – FORWARD TRANSMISSION COEFFICIENT versus FREQUENCY

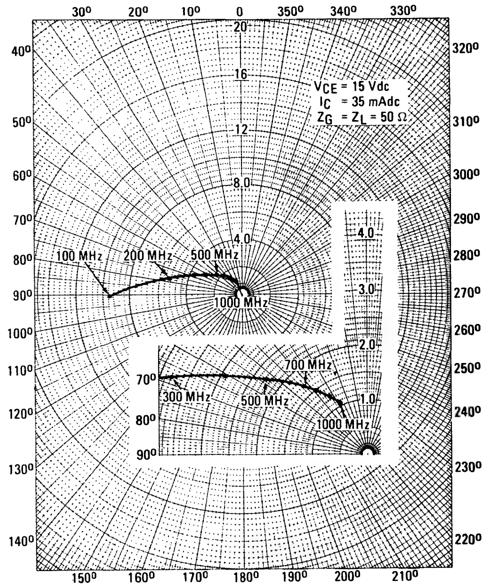
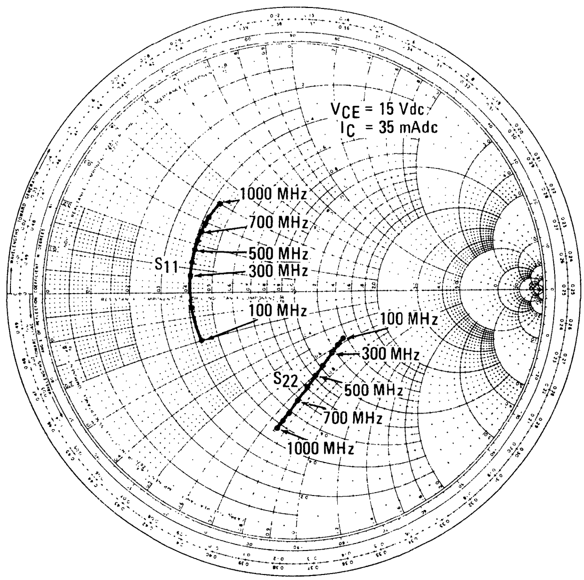



FIGURE 25 – INPUT REFLECTION COEFFICIENT AND OUTPUT REFLECTION COEFFICIENT versus FREQUENCY



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# 2N6304
# 2N6305

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTORS

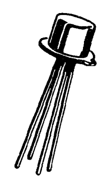
. . . designed for use as low-noise, high-gain, general-purpose amplifiers.

- High Current-Gain — Bandwidth Product —
  $f_T$ = 1.4 GHz (Min) @ $I_C$ = 10 mAdc – 2N6304
  = 1.2 GHz (Min) @ $I_C$ = 10 mAdc – 2N6305
- Low Noise Figure —
  NF = 4.5 dB (Max) @ f = 450 MHz – 2N6304
  = 5.5 dB (Max) @ f = 450 MHz – 2N6305
- High Power Gain —
  $G_{pe}$ = 15 dB (Min) @ f = 450 MHz – 2N6304
  = 12 dB (Min) @ f = 450 MHz – 2N6305

**1.4 GHz @ 10 mAdc – 2N6304**
**1.2 GHz @ 10 mAdc – 2N6305**

HIGH FREQUENCY TRANSISTORS

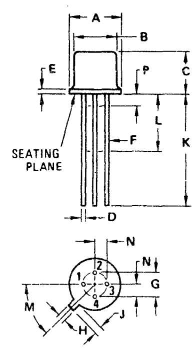
NPN SILICON



*MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage 1.0 to 20 mAdc | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 30 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current Continuous | $I_C$ | 50 | mAdc |
| Total Continuous Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.



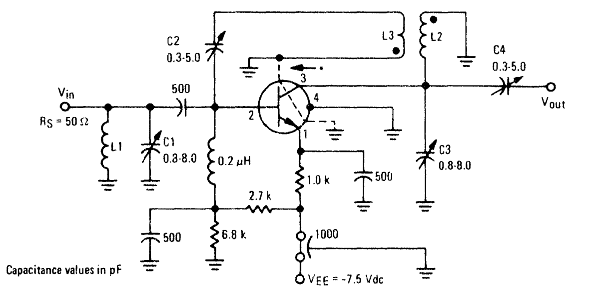

STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

CASE 20-03
TO-72

FIGURE 1 — TEST CIRCUIT FOR NOISE FIGURE AND POWER GAIN




L1, L2 – Silver-plated brass rod, 1-1/2" long and 1/4" dia. Install at least 1/2" from nearest vertical chassis surface.
L3 – 1/2 turn #16 AWG wire, located 1/4" from and parallel to L2.
* – External interlead shield to isolate collector lead from emitter and base leads.

Neutralization Procedure:
(A) Connect 450-MHz signal generator (with $R_S$ = 50 ohms) to input terminals of amplifier.
(B) Connect 50-ohm RF voltmeter across output terminals of amplifier.
(C) Apply $V_{EE}$, and with signal generator adjusted for 5 mV output from amplifier, tune C1, C3, and C4 for maximum output.
(D) Interchange connections to signal generator and RF voltmeter.
(E) With sufficient signal applied to output terminals of amplifier, adjust C2 for minimum indication at input.
(F) Repeat steps (A), (B), and (C) to determine if retuning is necessary.

***ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | | $BV_{CBO}$ | 30 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0) | | $I_{CBO}$ | – | – | 10 | nAdc |
| **ON CHARACTERISTICS** | | | | | | |
| DC Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc) | | $h_{FE}$ | 25 | – | 250 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 10 mAdc, $V_{CE}$ - 5.0 Vdc, f - 100 MHz) | 2N6304<br>2N6305 | $f_T$ | 1400<br>1200 | –<br>– | –<br>– | MHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | | $C_{cb}$ | – | 0.8 | 1.0 | pF |
| Small-Signal Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 1.0 kHz) | | $h_{fe}$ | 25 | – | 250 | – |
| Collector-Base Time Constant ($I_E$ = 2.0 mAdc, $V_{CB}$ = 5.0 Vdc, f = 31.8 MHz) | 2N6304<br>2N6305 | $r_b'C_c$ | 2.0<br>2.0 | – | 12<br>15 | ps |
| Noise Figure ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, $R_S$ = 50 ohms, f = 450 MHz) (Figure 1) | 2N6304<br>2N6305 | NF | –<br>– | –<br>– | 4.5<br>5.5 | dB |
| **FUNCTIONAL TEST** | | | | | | |
| Common-Emitter Amplifier Power Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 450 MHz) (Figure 1) | 2N6304<br>2N6305 | $G_{pe}$ | 15<br>12 | –<br>– | –<br>– | dB |

*Indicates JEDEC Registered Data.

**FIGURE 2 – COLLECTOR-BASE CAPACITANCE versus COLLECTOR BASE VOLTAGE**

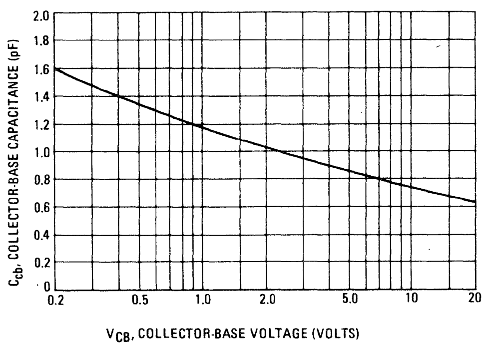


FIGURE 3 – CURRENT-GAIN-BANDWIDTH PRODUCT versus COLLECTOR CURRENT

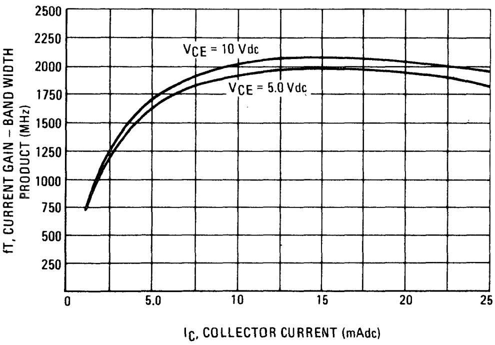



FIGURE 4 – COLLECTOR-BASE TIME CONSTANT versus EMITTER CURRENT

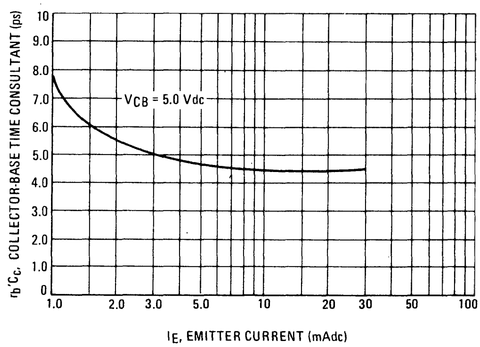



FIGURE 5 – REVERSE TRANSFER ADMITTANCE versus FREQUENCY

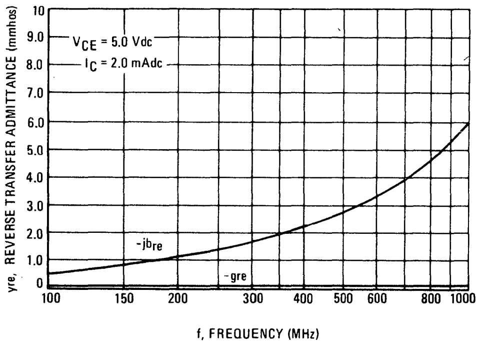



FIGURE 6 – INPUT ADMITTANCE versus FREQUENCY

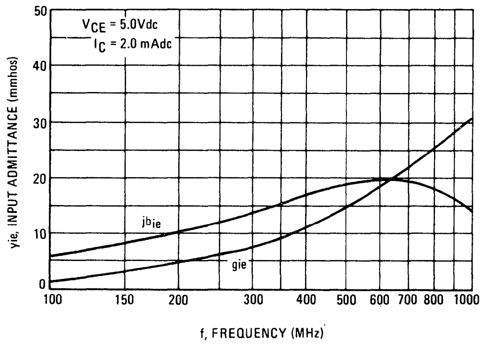



FIGURE 7 – OUTPUT ADMITTANCE versus FREQUENCY

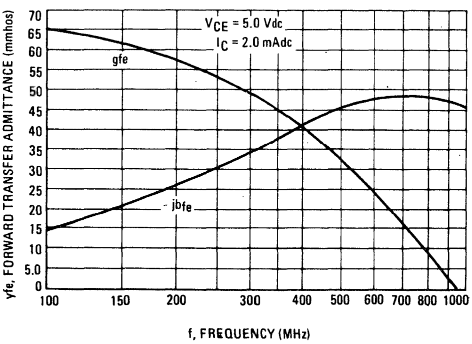



FIGURE 8 – FORWARD TRANSFER ADMITTANCE versus FREQUENCY

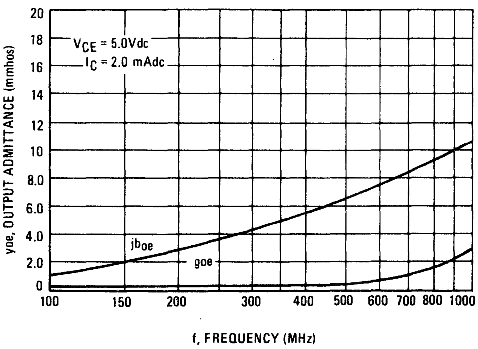


FIGURE 9 – $S_{11}$, INPUT REFLECTION COEFFICIENT

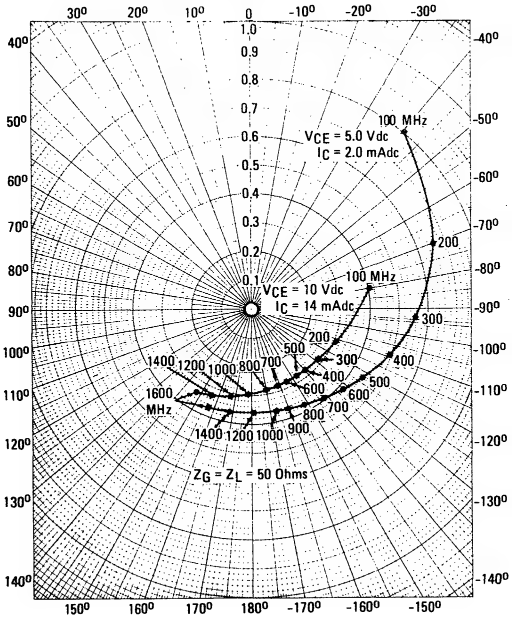



FIGURE 10 – $S_{22}$, OUTPUT REFLECTION COEFFICIENT

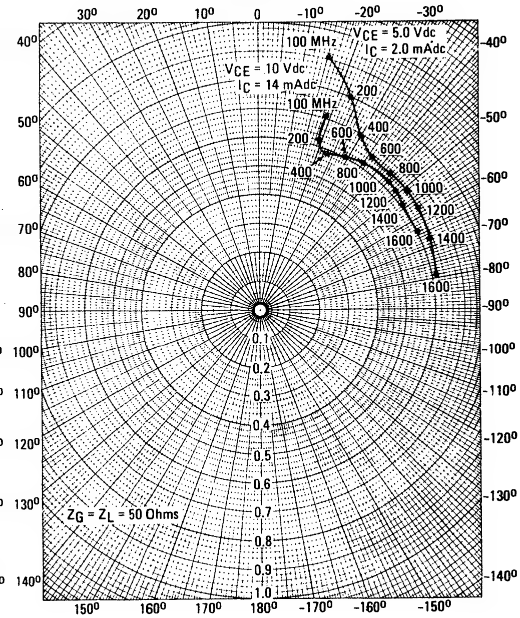



FIGURE 11 – $S_{12}$, REVERSE TRANSMISSION COEFFICIENT

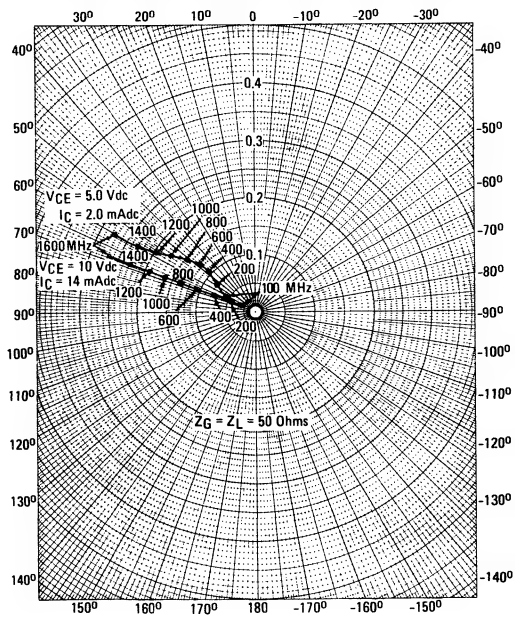



FIGURE 12 – $S_{21}$, FORWARD TRANSMISSION COEFFICIENT

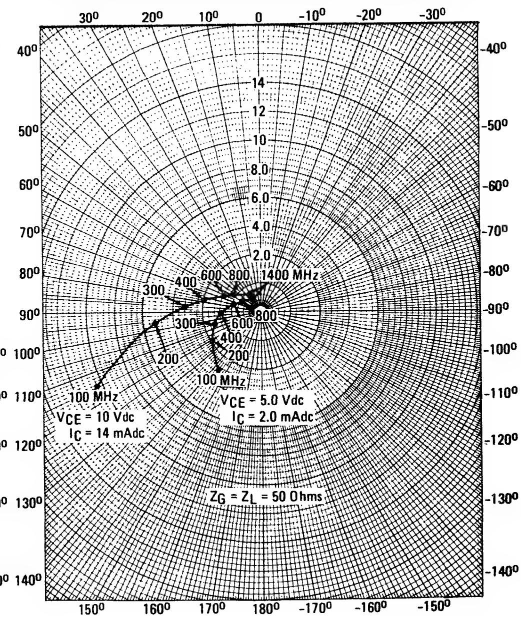
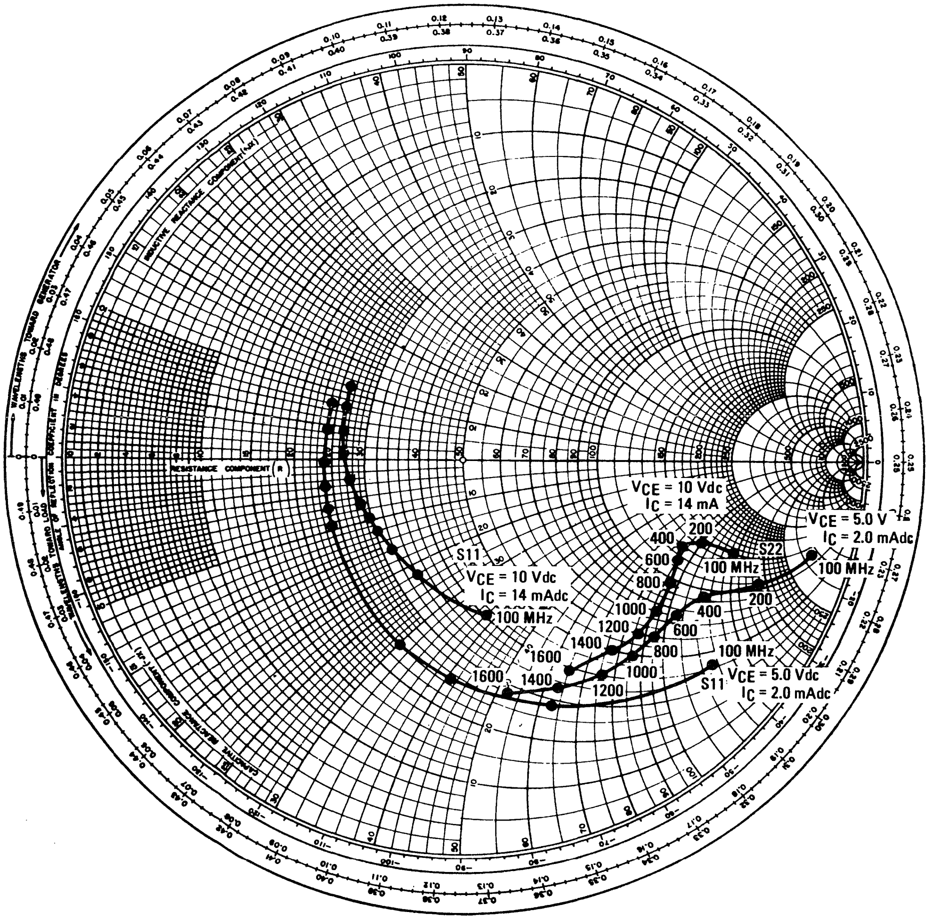


FIGURE 13 – $S_{11}$, INPUT REFLECTION COEFFICIENT AND $S_{22}$, OUTPUT REFLECTION COEFFICIENT



**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

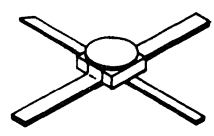
# 2N6603

## The RF Line

NF = 2.0 dB @ 1.0 GHz

**HIGH FREQUENCY TRANSISTOR**

NPN SILICON



### NPN SILICON HIGH FREQUENCY TRANSISTOR

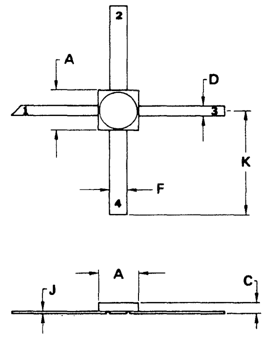
. . . designed for use in high-gain, low-noise, small signal, narrow and wideband amplifiers. Ideal for use in microstrip thin and thick film applications.

- Low Noise Figure –
  NF = 2.0 dB (Typ) @ f = 1.0 GHz
  = 2.9 dB (Typ) @ f = 2.0 GHz
- High Power Gain –
  MAG = 17 dB (Typ) @ f = 1.0 GHz
  = 11 dB (Typ) @ f = 2.0 GHz
- Ion Implantation and Gold Metallization Construction Techniques
- Metal/Ceramic Hermatic Package
- JAN, JTX, JTXV Available

***MAXIMUM RATINGS ($T_A$ = 25°C Free Air Temperature)**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 25 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current—Continuous | $I_C$ | 30 | mAdc |
| Total Device Dissipation @ $T_C$ = 100°C | $P_D$ | 400 | mW |
| Derate Above 100°C | | 4.0 | mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data




| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 2.29 | 2.67 | 0.090 | 0.105 |
| C | 0.89 | 1.40 | 0.035 | 0.055 |
| D | 0.41 | 0.61 | 0.016 | 0.024 |
| F | 0.89 | 1.09 | 0.035 | 0.043 |
| J | 0.08 | 0.15 | 0.003 | 0.006 |
| K | 4.45 | 5.84 | 0.175 | 0.230 |

NOTE:
1. DIMENSION K APPLIES TO ALL LEADS.

STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

CASE 303-01

**Specification and Package Options**

Devices using the same die type as the 2N6603:

MRF901 – 4 Lead Plastic Macro-T Case 302-01
MRF902 – 100 mil Metal/Ceramic Case 303-01
MRF904 – TO-72
MMBR901 – MiniBloc Plastic (SOT-23) TO-236
MRFC901 – Unencapsulated Chip

Complete data sheet in preparation. Contact your Motorola representative or Motorola Semiconductor Products Inc., Literature Distribution Center, P.O. Box 20924, Phoenix, AZ 85036.

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# 2N6604

## The RF Line

NF = 2.5 dB @ 1.0 GHz

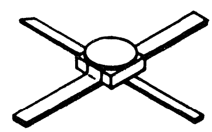
**HIGH FREQUENCY TRANSISTOR**

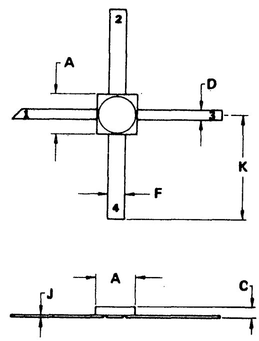
NPN SILICON

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for use in high-frequency, low-noise, small-signal, narrow and wideband amplifiers. Ideal for use in microstrip thin and thick film applications.

- Low Noise Figure — NF = 2.5 dB (Typ) @ f = 1.0 GHz
- High Power Gain — MAG = 16 dB (Typ) @ f = 1.0 GHz
- High Current—Specified Performance @ $I_C$ = 30 mA
- Ion Implantation and Gold Metallization Construction Techniques
- Metal/Ceramic Hermetic Package
- JAN, JTX, JTXV Available






| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 2.29 | 2.67 | 0.090 | 0.105 |
| C | 0.89 | 1.40 | 0.035 | 0.055 |
| D | 0.41 | 0.61 | 0.016 | 0.024 |
| F | 0.89 | 1.09 | 0.035 | 0.043 |
| J | 0.08 | 0.15 | 0.003 | 0.006 |
| K | 4.45 | 5.84 | 0.175 | 0.230 |

NOTE:
1. DIMENSION K APPLIES TO ALL LEADS.

STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

CASE 303-01

### *MAXIMUM RATINGS ($T_A$ = 25°C Free Air Temperature)

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 25 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current—Continuous | $I_C$ | 50 | mAdc |
| Total Device Dissipation @ $T_C$ = 75°C<br>Derate Above 75°C | $P_D$ | 500<br>4.0 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

*Indicates JEDEC Registered Data.

**Specifications and Package Options**

Devices using the same die type as the 2N6604:

| | |
|---|---|
| MRF911 | – 4 Lead Plastic Macro-T Case 302-01 |
| MRF912 | – 100 mil Metal/Ceramic Case 303-01 |
| MRF914 | – TO-72 |
| MMBR930 | – MiniBloc Plastic (SOT-23) TO-236 |
| BFR91 | – 3 Lead Plastic Macro-T Case 302A-01 |
| BFRC91 | – Unencapsulated Chip |

Complete data sheet in preparation. Contact your Motorola representative or Motorola Semiconductor Products Inc., Literature Distribution Center, P.O. Box 20924, Phoenix, AZ 85036.

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# BFR90

## Advance Information

## The RF Line

$f_T$ = 5.0 GHz @ 14 mA

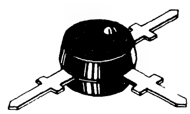
**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed primarily for use in high-gain, low-noise, small-signal amplifiers. Also used in applications requiring fast switching times.

- High Current-Gain – Bandwidth Product –
  $f_T$ = 5.0 GHz (Typ) @ $I_C$ = 14 mA
- Low Noise Figure –
  NF = 2.4 dB (Typ) @ f = 0.5 GHz
  = 3.0 dB (Typ) @ f = 1.0 GHz
- High Power Gain –
  $G_{max}$ = 18 dB (Typ) @ f = 0.5 GHz
  = 12 dB (Typ) @ f = 1.0 GHz

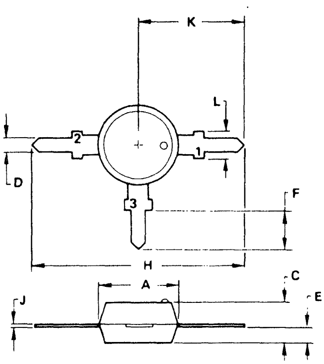


**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 30 | mAdc |
| Total Device Dissipation @ $T_A$ = 60°C | $P_D$ | 180 | mW |
| Derate Above 60°C | | 2.0 | mW/°C |
| Storage Temperature Range | $T_{stg}$ | –65 to +150 | °C |

**THERMAL CHARACTERISTICS**

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance Junction to Ambient | $R_{\theta JA}$ | 500 | °C/W |

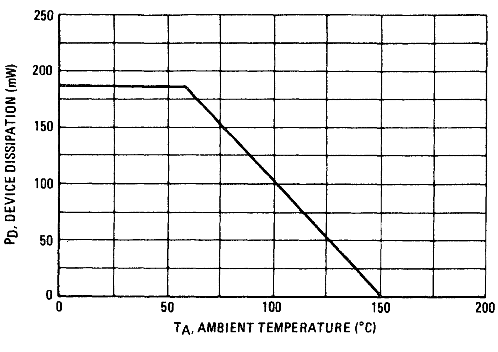



STYLE 1:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | – | 4.78 | – | 0.188 |
| C | – | 3.05 | – | 0.120 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 0.97 | 1.22 | 0.038 | 0.048 |
| F | 2.21 | 2.46 | 0.087 | 0.097 |
| H | 12.40 | 12.90 | 0.488 | 0.508 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 6.20 | 6.45 | 0.244 | 0.254 |
| L | 1.40 | 1.65 | 0.055 | 0.065 |

**CASE 302A-01**

FIGURE 1 – POWER DERATING




This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 20 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 14 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 25 | – | 250 | – |
| **DYNAMIC CHARACTERTISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C$ = 14 mAdc, $V_{CE}$ = 10 Vdc, f = 0.5 GHz) | $f_T$ | – | 5.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.5 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 0.5 GHz) | | – | 2.4 | – | |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 3.0 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 0.5 GHz) | | – | 15 | – | |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 10 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 14 mAdc, $V_{CE}$ = 10 Vdc, f = 0.5 GHz) | | – | 18 | – | |
| ($I_C$ = 14 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 12 | – | |

(1) $G_{max} = \dfrac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

FIGURE 2 – POWER GAIN AND NOISE FIGURE versus FREQUENCY

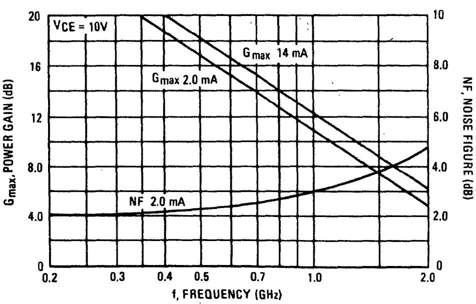



FIGURE 3 – POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT

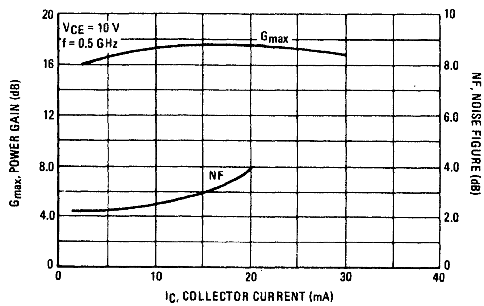


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ |
| 5.0 | 2.0 | 0.77 | -45 | 0.48 | -90 | 0.33 | -125 | 0.27 | -160 | 0.28 | 170 |
| | 5.0 | 0.52 | -60 | 0.25 | -110 | 0.18 | -150 | 0.18 | 170 | 0.21 | 145 |
| | 10 | 0.33 | -75 | 0.15 | -125 | 0.13 | -175 | 0.15 | 150 | 0.20 | 130 |
| | 20 | 0.20 | -95 | 0.12 | -155 | 0.14 | 165 | 0.17 | 145 | 0.22 | 130 |
| | 30 | 0.17 | -116 | 0.14 | -170 | 0.17 | 160 | 0.21 | 145 | 0.26 | 130 |
| 10 | 2.0 | 0.79 | -40 | 0.50 | -80 | 0.33 | -115 | 0.26 | -150 | 0.25 | 175 |
| | 5.0 | 0.56 | -55 | 0.27 | -95 | 0.16 | -135 | 0.13 | -175 | 0.17 | 150 |
| | 10 | 0.39 | -65 | 0.16 | -105 | 0.10 | -150 | 0.10 | 165 | 0.15 | 140 |
| | 20 | 0.25 | -75 | 0.10 | -120 | 0.09 | -175 | 0.12 | 150 | 0.18 | 130 |
| | 30 | 0.25 | -75 | 0.10 | -120 | 0.09 | -175 | 0.12 | 150 | 0.18 | 130 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| 5.0 | 2.0 | 0.89 | -20 | 0.69 | -30 | 0.61 | -35 | 0.55 | -35 | 0,52 | -45 |
| | 5.0 | 0.75 | -25 | 0.55 | -30 | 0.50 | -30 | 0.47 | -30 | 0.43 | -40 |
| | 10 | 0.64 | -25 | 0.49 | -25 | 0.45 | -25 | 0.43 | -30 | 0.40 | -35 |
| | 20 | 0.57 | -25 | 0.47 | -20 | 0.44 | -25 | 0.43 | -25 | 0.40 | -35 |
| | 30 | 0.55 | -20 | 0.47 | -20 | 0.46 | -20 | 0.44 | -25 | 0.42 | -35 |
| 10 | 2.0 | 0.91 | -15 | 0.74 | -25 | 0.66 | -30 | 0.62 | -35 | 0.59 | -40 |
| | 5.0 | 0.79 | -20 | 0.61 | -25 | 0.56 | -25 | 0.54 | -30 | 0.51 | -35 |
| | 10 | 0.70 | -20 | 0.56 | -20 | 0.53 | -25 | 0.51 | -25 | 0.48 | -35 |
| | 20 | 0.63 | -20 | 0.54 | -25 | 0.53 | -20 | 0.51 | -25 | 0.49 | -35 |
| | 30 | 0.63 | -15 | 0.56 | -15 | 0.55 | -20 | 0.54 | -25 | 0.52 | -35 |

FIGURE 6 – $S_{21}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| 5.0 | 2.0 | 5.76 | 140 | 3.81 | 105 | 2.73 | 90 | 2.20 | 75 | 1.70 | 60 |
| | 5.0 | 9.92 | 125 | 5.24 | 95 | 3.50 | 80 | 2.80 | 70 | 2.10 | 60 |
| | 10 | 12.33 | 115 | 5.82 | 90 | 3.79 | 75 | 2.90 | 65 | 2.20 | 55 |
| | 20 | 13.62 | 105 | 6.00 | 85 | 3.88 | 75 | 2.95 | 65 | 2.25 | 55 |
| | 30 | 13.41 | 105 | 5.80 | 80 | 3.74 | 75 | 2.85 | 65 | 2.15 | 55 |
| 10 | 2.0 | 5.77 | 145 | 3.88 | 110 | 2.80 | 90 | 2.25 | 75 | 1.75 | 60 |
| | 5.0 | 10.05 | 130 | 5.42 | 95 | 3.60 | 80 | 2.85 | 70 | 2.10 | 60 |
| | 10 | 12.56 | 115 | 6.00 | 90 | 3.90 | 80 | 3.05 | 70 | 2.25 | 55 |
| | 20 | 13.77 | 110 | 6.13 | 85 | 3.92 | 75 | 3.05 | 65 | 2.20 | 55 |
| | 30 | 13.23 | 105 | 5.79 | 85 | 3.70 | 75 | 2.85 | 65 | 2.15 | 55 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 5.0 | 2.0 | 0.06 | 65 | 0.10 | 55 | 0.12 | 55 | 0.14 | 55 | 0.17 | 60 |
| | 5.0 | 0.05 | 65 | 0.08 | 65 | 0.12 | 65 | 0.15 | 65 | 0.19 | 65 |
| | 10 | 0.04 | 65 | 0.08 | 70 | 0.12 | 70 | 0.15 | 70 | 0.20 | 65 |
| | 20 | 0.04 | 75 | 0.08 | 75 | 0.12 | 75 | 0.15 | 70 | 0.20 | 70 |
| | 30 | 0.03 | 75 | 0.07 | 75 | 0.11 | 75 | 0.15 | 75 | 0.19 | 70 |
| 10 | 2.0 | 0.05 | 70 | 0.03 | 55 | 0.11 | 55 | 0.12 | 55 | 0.15 | 60 |
| | 5.0 | 0.04 | 65 | 0.07 | 65 | 0.10 | 65 | 0.13 | 65 | 0.17 | 70 |
| | 10 | 0.04 | 65 | 0.07 | 70 | 0.10 | 70 | 0.13 | 70 | 0.17 | 70 |
| | 20 | 0.03 | 70 | 0.07 | 75 | 0.10 | 75 | 0.13 | 75 | 0.17 | 70 |
| | 30 | 0.03 | 75 | 0.06 | 75 | 0.10 | 75 | 0.13 | 75 | 0.17 | 70 |

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# BFR91

## Advance Information

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

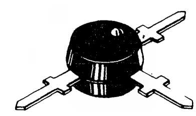
. . . designed primarily for use in high-gain, low-noise, small-signal amplifiers. Also used in applications requiring fast switching times.

- High Current-Gain — Bandwidth Product — $f_T$ = 5.0 GHz (Typ) @ $I_C$ = 30 mA
- Low Noise Figure — NF = 1.9 dB (Typ) @ f = 0.5 GHz
- High Power Gain — $G_{max}$ = 16 dB (Typ) @ f = 0.5 GHz

$f_T$ = 5.0 GHz @ 30 mA

HIGH FREQUENCY TRANSISTOR

NPN SILICON

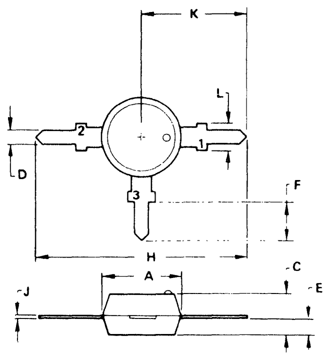


**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 12 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 15 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 35 | mAdc |
| Total Device Dissipation @ $T_A$ = 60°C | $P_D$ | 180 | mW |
| Derate Above 60°C | | 2.0 | mW/°C |
| Storage Temperature Range | $T_{stg}$ | −65 to +150 | °C |

**THERMAL CHARACTERISTICS**

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance Junction to Ambient | $R_{\theta JA}$ | 500 | °C/W |

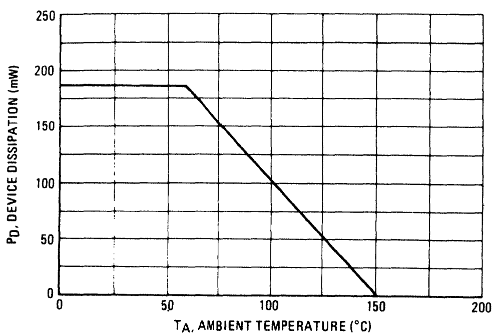



STYLE 1:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | – | 4.78 | – | 0.188 |
| C | – | 3.05 | – | 0.120 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 0.97 | 1.22 | 0.038 | 0.048 |
| F | 2.21 | 2.46 | 0.087 | 0.097 |
| H | 12.40 | 12.90 | 0.488 | 0.508 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 6.20 | 6.45 | 0.244 | 0.254 |
| L | 1.40 | 1.65 | 0.055 | 0.065 |

**CASE 302A-01**

FIGURE 1 – POWER DERATING




This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 12 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 15 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 30 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 25 | – | 250 | – |
| **DYNAMIC CHARACTERTISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C$ = 30 mAdc, $V_{CE}$ = 5.0 Vdc, f = 0.5 GHz) | $f_T$ | – | 5.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.7 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 0.5 GHz) | | – | 1.9 | – | |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 1.0 GHz) | | – | 2.5 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 0.5 GHz) | | – | 11 | – | |
| ($I_C$ = 2.0 mAdc, $V_{CE}$ = 5.0 Vdc, f = 1.0 GHz) | | – | 8.0 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 5.0 Vdc, f = 0.5 GHz) | | – | 16 | – | |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 5.0 Vdc, f = 1.0 GHz) | | – | 10 | – | |

(1) $G_{max} = \dfrac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

**FIGURE 2 - POWER GAIN AND NOISE FIGURE versus FREQUENCY**

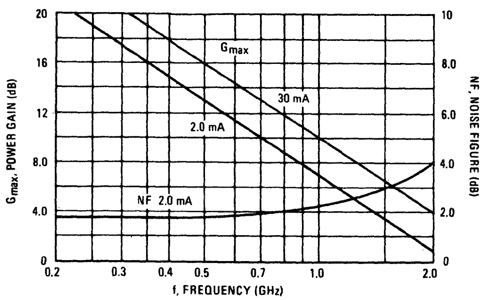



**FIGURE 3 - POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT**

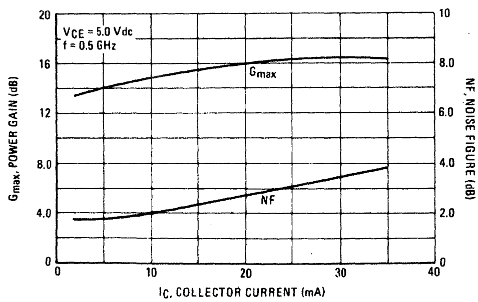


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ |
| | 2.0 | 0.72 | -65 | 0.51 | -125 | 0.46 | -165 | 0.47 | 170 | 0.51 | 145 |
| | 5.0 | 0.49 | -90 | 0.35 | -150 | 0.34 | 175 | 0.36 | 155 | 0.41 | 135 |
| 5.0 | 10 | 0.34 | -110 | 0.28 | -165 | 0.29 | 165 | 0.32 | 145 | 0.36 | 130 |
| | 20 | 0.26 | -130 | 0.24 | 180 | 0.27 | 155 | 0.30 | 140 | 0.34 | 125 |
| | 30 | 0.24 | -145 | 0.24 | 175 | 0.27 | 155 | 0.30 | 140 | 0.34 | 125 |
| | 2.0 | 0.74 | -60 | 0.51 | -120 | 0.45 | -160 | 0.45 | 170 | 0.49 | 150 |
| | 5.0 | 0.52 | -80 | 0.33 | -140 | 0.31 | -175 | 0.32 | 160 | 0.37 | 145 |
| 10 | 10 | 0.36 | -95 | 0.24 | -155 | 0.24 | 170 | 0.27 | 155 | 0.31 | 140 |
| | 20 | 0.25 | -115 | 0.19 | -170 | 0.21 | 160 | 0.24 | 145 | 0.29 | 130 |
| | 30 | 0.22 | -120 | 0.19 | -175 | 0.21 | 160 | 0.25 | 145 | 0.20 | 130 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| | 2.0 | 0.83 | -25 | 0.62 | -35 | 0.55 | -40 | 0.51 | -45 | 0.49 | -60 |
| | 5.0 | 0.66 | -30 | 0.45 | -35 | 0.40 | -40 | 0.37 | -40 | 0.34 | -50 |
| 5.0 | 10 | 0.52 | -35 | 0.36 | -35 | 0.32 | -35 | 0.30 | -35 | 0.27 | -50 |
| | 20 | 0.42 | -35 | 0.30 | -30 | 0.27 | -30 | 0.26 | -30 | 0.22 | -45 |
| | 30 | 0.38 | -35 | 0.28 | -25 | 0.26 | -30 | 0.25 | -30 | 0.21 | -40 |
| | 2.0 | 0.86 | -20 | 0.67 | -30 | 0.62 | -35 | 0.58 | -40 | 0.56 | -50 |
| | 5.0 | 0.71 | -25 | 0.53 | -30 | 0.48 | -30 | 0.45 | -35 | 0.43 | -45 |
| 10 | 10 | 0.59 | -30 | 0.45 | -25 | 0.41 | -30 | 0.40 | -30 | 0.37 | -40 |
| | 20 | 0.50 | -25 | 0.40 | -25 | 0.38 | -25 | 0.37 | -30 | 0.34 | -40 |
| | 30 | 0.47 | -25 | 0.40 | -20 | 0.38 | -25 | 0.37 | -30 | 0.34 | -35 |

FIGURE 6 – $S_{21}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| | 2.0 | 5.25 | 130 | 3.06 | 95 | 2.10 | 75 | 1.70 | 65 | 1.20 | 50 |
| | 5.0 | 8.72 | 120 | 4.34 | 90 | 2.84 | 75 | 2.30 | 65 | 1.60 | 50 |
| 5.0 | 10 | 10.85 | 110 | 4.92 | 85 | 3.22 | 70 | 2.60 | 65 | 1.80 | 50 |
| | 20 | 12.13 | 105 | 5.34 | 80 | 3.44 | 70 | 2.75 | 60 | 1.90 | 50 |
| | 30 | 12.50 | 100 | 5.42 | 80 | 3.47 | | 2.75 | 60 | 1.90 | 50 |
| | 2.0 | 5.36 | 135 | 3.20 | 95 | 2.20 | 80 | 1.85 | 65 | 1.30 | 50 |
| 10 | 5.0 | 9.05 | 120 | 4.55 | 90 | 3.00 | 75 | 2.45 | 65 | 1.65 | 50 |
| | 10 | 11.37 | 110 | 5.22 | 85 | 3.40 | 75 | 2.65 | 65 | 1.85 | 50 |
| | 20 | 12.83 | 105 | 5.64 | 80 | 3.63 | 70 | 2.75 | 60 | 2.00 | 50 |
| | 30 | 13.10 | 100 | 5.62 | 80 | 3.63 | 70 | 2.75 | 60 | 2.00 | 50 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 200 | | 500 | | 800 | | 1000 | | 1500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| | 2.0 | 0.08 | 55 | 0.11 | 45 | 0.12 | 50 | 0.14 | 55 | 0.17 | 65 |
| | 5.0 | 0.06 | 55 | 0.09 | 60 | 0.13 | 65 | 0.17 | 65 | 0.22 | 65 |
| 5.0 | 10 | 0.05 | 60 | 0.09 | 65 | 0.14 | 70 | 0.19 | 65 | 0.24 | 65 |
| | 20 | 0.05 | 70 | 0.07 | 70 | 0.15 | 70 | 0.19 | 70 | 0.25 | 65 |
| | 30 | 0.04 | 75 | 0.10 | 75 | 0.15 | 70 | 0.19 | 70 | 0.25 | 65 |
| | 2.0 | 0.06 | 60 | 0.09 | 45 | 0.10 | 50 | 0.12 | 60 | 0.15 | 70 |
| | 5.0 | 0.05 | 60 | 0.08 | 60 | 0.11 | 65 | 0.15 | 65 | 0.19 | 70 |
| 10 | 10 | 0.05 | 65 | 0.08 | 65 | 0.12 | 70 | 0.16 | 70 | 0.21 | 70 |
| | 20 | 0.04 | 70 | 0.08 | 70 | 0.13 | 70 | 0.17 | 70 | 0.22 | 70 |
| | 30 | 0.04 | 70 | 0.08 | 75 | 0.13 | 70 | 0.17 | 70 | 0.22 | 70 |

**MOTOROLA Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MD4957

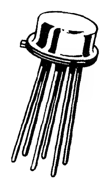
## DUAL PNP SILICON ANNULAR* 450-MHz AMPLIFIER

. . . designed for high-gain, low-noise amplifier, oscillator, and mixer applications.

- Low Noise Figure — NF = 2.6 dB (Typ) @ 450 MHz
  5.0 dB (Typ) @ 1.0 GHz
- High Power Gain — Gpe = 18 dB (Typ) @ 450 MHz
  13 dB (Typ) @ 1.0 GHz
- High Gain-Bandwidth Product — fT = 1500 MHz (Typ)
- Low Collector-Base Capacitance — $C_{cb}$ = 0.4 pF (Typ)

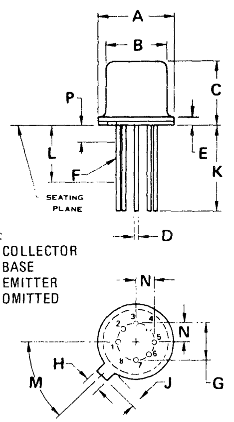
**MULTIPLE DEVICES**

**DUAL PNP SILICON AMPLIFIER**



### MAXIMUM RATINGS (each side)

| Rating | Symbol | Value | | Unit |
|---|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 30 | | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.0 | | Vdc |
| Collector Current | $I_C$ | 30 | | mAdc |
| Operating and Storage Junction Temperature Range | $T_J$, $T_{stg}$ | -65 to +200 | | °C |
| | | One Side | Both Sides | |
| Total Device Dissipation @ $T_A$ = 25°C | $P_D$ | 200 | 400 | mW |
| Derate above 25°C | | 1.15 | 2.3 | mW/°C |

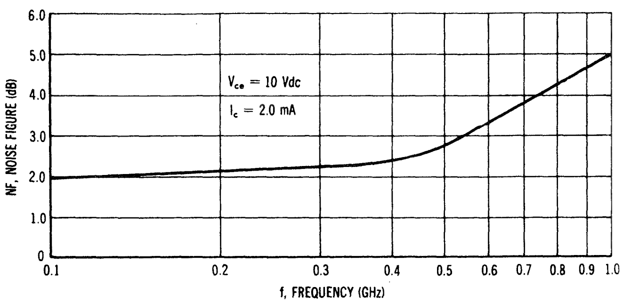



STYLE 1:
PIN 1. COLLECTOR
2. BASE
3. EMITTER
4. OMITTED

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.51 | 9.40 | 0.335 | 0.370 |
| B | 7.75 | 8.51 | 0.305 | 0.335 |
| C | 4.19 | 4.70 | 0.165 | 0.185 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 1.02 | – | 0.040 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 5.08 BSC | | 0.200 BSC | |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.14 | 0.029 | 0.045 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 2.54 | | 0.100 BSC | |
| P | – | 1.27 | – | 0.050 |

654-02

### TYPICAL NOISE FIGURE vs. FREQUENCY

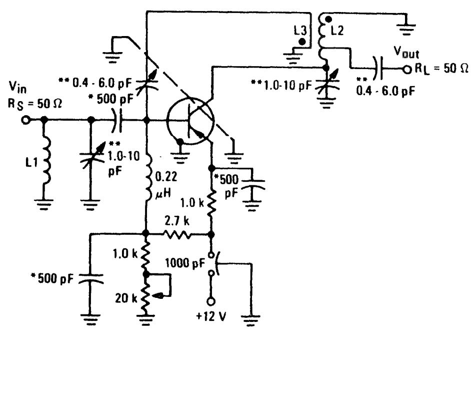



* Annular Semiconductors patented by Motorola Inc.

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 30 | - | - | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 30 | - | - | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | - | - | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 20 Vdc, $I_E$ = 0) | $I_{CBO}$ | - | - | 0.1 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | - | 150 | - |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 100 MHz) | $f_T$ | 1000 | 1500 | - | MHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 100 kHz) | $C_{cb}$ | - | 0.4 | 0.8 | pF |
| Small-Signal Current Gain ($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 kHz) | $h_{fe}$ | 20 | - | 200 | - |
| Collector-Base Time Constant ($I_E$ = 2.0 mAdc, $V_{CB}$ = 10 Vdc, f = 63.6 MHz) | $r_b'C_c$ | - | 4.0 | 8.0 | ps |
| Noise Figure<br>($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, f = 450 MHz) Figure 1<br>($I_C$ = 2.0 mAdc, $V_{CE}$ = 10 Vdc, $R_S$ = 50 ohms, f = 1.0 GHz) | NF | -<br>- | 2.6<br>5.0 | -<br>- | dB |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain<br>($V_{CE}$ = 10 Vdc, $I_C$ = 2.0 mAdc, f = 450 MHz)<br>($V_{CE}$ = 10 Vdc, $I_C$ = 2.0 mAdc, $R_S$ = 50 ohms, f = 1.0 GHz) | $G_{pe}$ | -<br>- | 18<br>13 | -<br>- | dB |

**FIGURE 1 — NOISE FIGURE AND POWER GAIN TEST CIRCUIT**




* Button type capacitors
** Variable air piston type capacitors

1. L1 - silver plated brass bar, 1.0 in. lg by 0.25 in od.
2. L2 - silver plated brass bar, 1.5 in. lg by 0.25 in od. Tap is 0.25 in. from collector
3. L3 - ½ turn of AWG No. 16 wire 0.25 in. from and parallel to L2.
4. The noise source is a hot-cold body (All type 70 or equivalent) with a test receiver (AIL type 136 or equivalent).

## COMMON EMITTER Y PARAMETER VARIATIONS

### Y PARAMETERS VS FREQUENCY

$V_{CE} = 10$ Vdc

$I_C = 2.0$ mA

FIGURE 2 — INPUT ADMITTANCE

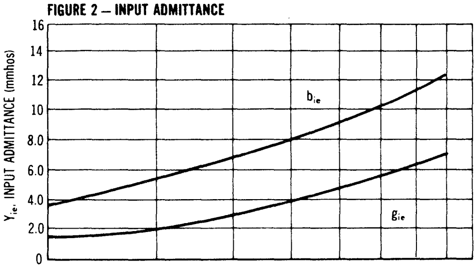



FIGURE 3 — FORWARD TRANSFER ADMITTANCE

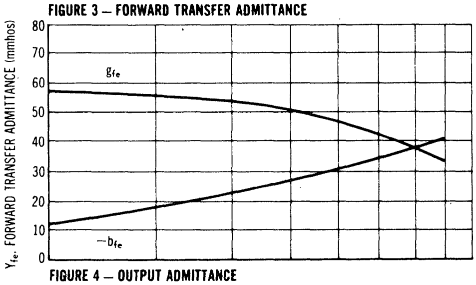



FIGURE 4 — OUTPUT ADMITTANCE

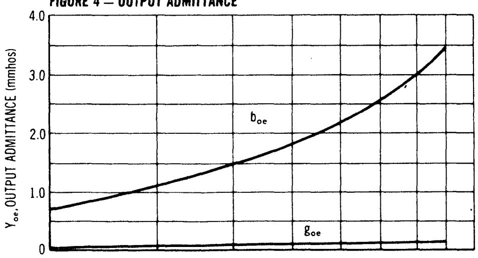
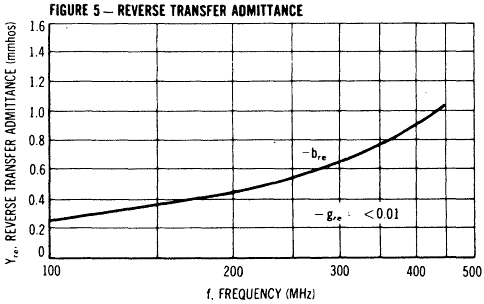



FIGURE 5 — REVERSE TRANSFER ADMITTANCE




### Y PARAMETERS VS CURRENT

$V_{CE} = 10$ Vdc ——— $V_{CE} = 15$ Vdc — — —

f = 450 MHz

FIGURE 6 — INPUT ADMITTANCE

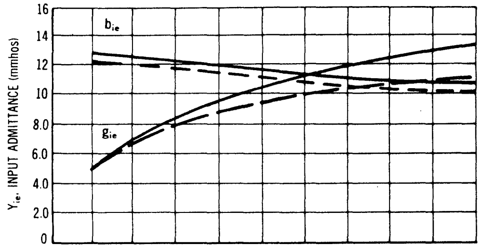



FIGURE 7 — FORWARD TRANSFER ADMITTANCE

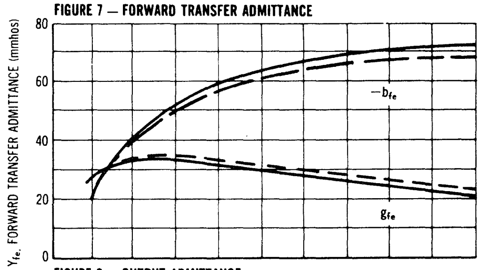



FIGURE 8 — OUTPUT ADMITTANCE

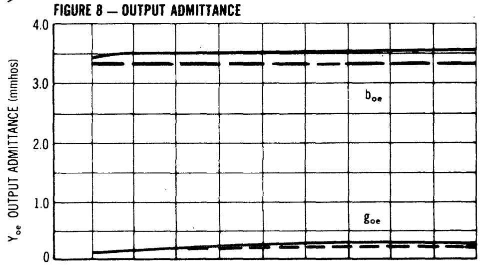
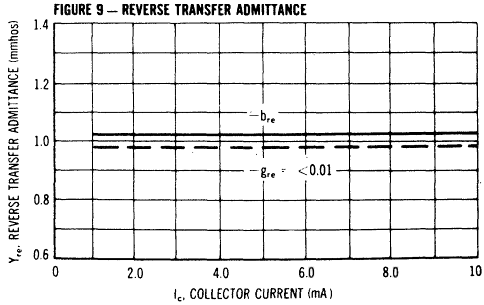



FIGURE 9 — REVERSE TRANSFER ADMITTANCE



## COMMON BASE Y PARAMETER VARIATIONS

### Y PARAMETERS versus FREQUENCY

$V_{CB} = 10$ Vdc

$I_C = 2.0$ mA

FIGURE 10 — INPUT ADMITTANCE

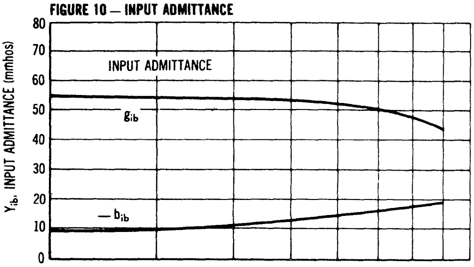



FIGURE 11 — FORWARD TRANSFER ADMITTANCE

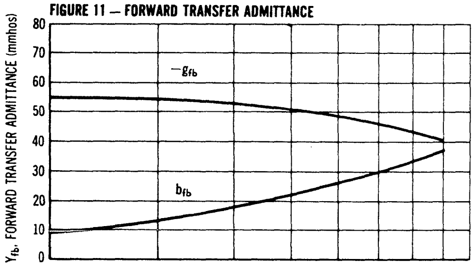



FIGURE 12 — OUTPUT ADMITTANCE

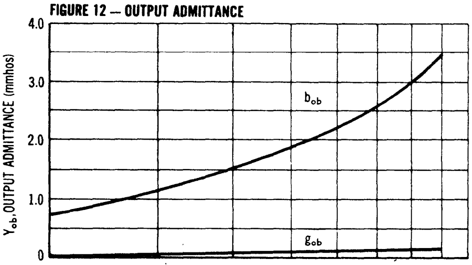
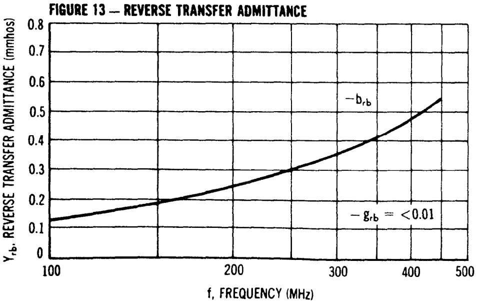



FIGURE 13 — REVERSE TRANSFER ADMITTANCE




### Y PARAMETERS versus CURRENT

$V_{CB} = 10$ Vdc ——— $V_{CB} = 15$ Vdc — — —

f = 450 MHz

FIGURE 14 — INPUT ADMITTANCE

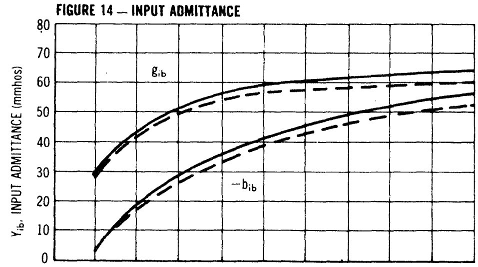



FIGURE 15 — FORWARD TRANSFER ADMITTANCE

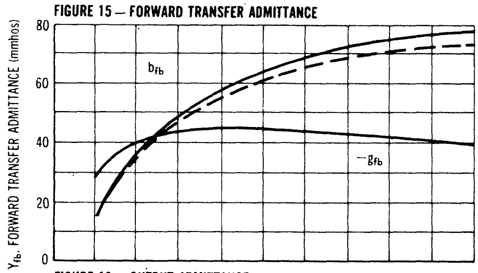



FIGURE 16 — OUTPUT ADMITTANCE

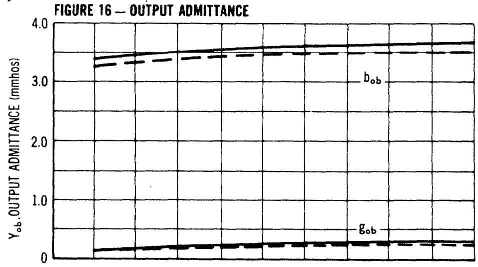
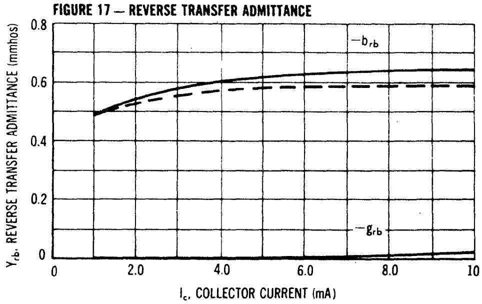



FIGURE 17 — REVERSE TRANSFER ADMITTANCE



MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MM4049

## The RF Line

4.0 GHz @ 20 mAdc

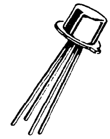
HIGH FREQUENCY TRANSISTOR

PNP SILICON

### PNP SILICON HIGH-FREQUENCY TRANSISTOR

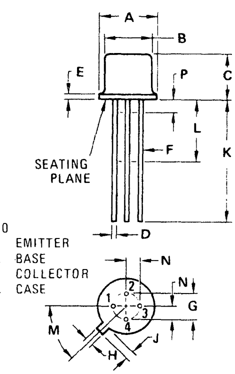
. . . designed for use as a high-frequency current mode switch. Because of the extremely high Current-Gain—Bandwidth this transistor also makes an excellent RF amplifier and oscillator.

- High Current-Gain—Bandwidth Product — $f_T$ = 4.0 GHz (Min) @ $I_C$ = 20 mAdc
- Low Collector-Base Capacitance — $C_{cb}$ = 1.25 pF (Max) @ $V_{CB}$ = 5.0 Vdc



### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 10 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 15 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 4.5 | Vdc |
| Collector Current — Continuous | $I_C$ | 30 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 200<br>1.14 | mW<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |



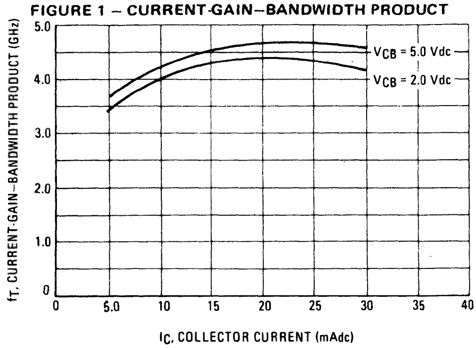

STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45°BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

CASE 20-03
TO-72

FIGURE 1 — CURRENT-GAIN—BANDWIDTH PRODUCT



**ELECTRICAL CHARACTERISTICS** ($T_A = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 2.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 10 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 15 | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 4.5 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 10 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | 10 | nAdc |
| **ON CHARACTERISTICS** | | | | |
| DC Current Gain ($I_C$ = 25 mAdc, $V_{CE}$ = 2.0 Vdc) | $h_{FE}$ | 20 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | |
| Current-Gain—Bandwidth Product (Figure 1) ($I_C$ = 20 mAdc, $V_{CE}$ = 5.0 Vdc, f = 500 MHz) | $f_T$ | 4.0 | – | GHz |
| Collector-Base Capacitance (Figure 2) ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 1.25 | pF |
| Emitter-Base Capacitance (Figure 2) ($V_{EB}$ = 0.5 Vdc, $I_C$ = 0, f = 1.0 MHz) | $C_{eb}$ | – | 1.25 | pF |
| Collector-Base Time Constant (Figure 3) ($I_E$ = 15 mAdc, $V_{CB}$ = 5.0 Vdc, f = 63.6 MHz) | $r_b'C_c$ | – | 15 | ps |

FIGURE 2 — CAPACITANCES

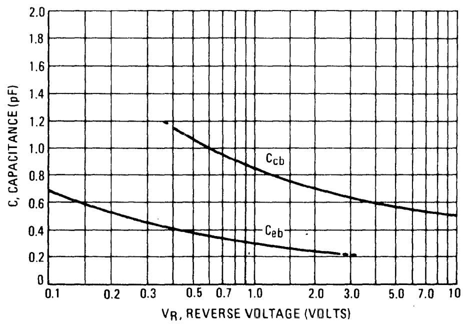
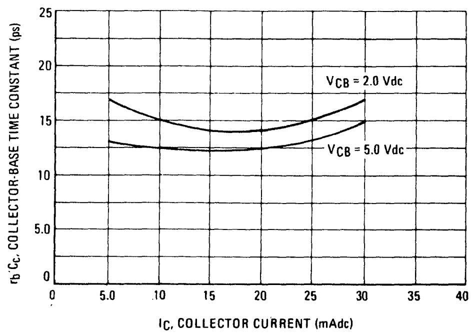



FIGURE 3 — COLLECTOR-BASE TIME CONSTANT



MOTOROLA
Semiconductors
BOX 20912 • PHOENIX, ARIZONA 85036

# MM8000
# MM8001

## Advance Information

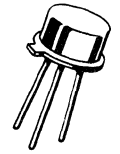
## The RF Line

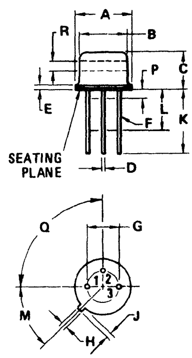
NPN SILICON
AMPLIFIER
TRANSISTORS

### NPN SILICON HIGH-FREQUENCY TRANSISTOR

. . . designed for high-frequency C.A.T.V. amplifier applications. Suitable for use as output driver or pre-driver stages in VHF and UHF equipment.

- High Current-Gain—Bandwidth Product — $f_T$ = 900 MHz (Min) @ $I_C$ = 50 mAdc (MM8001)
- Low Output Capacitance — $C_{ob}$ = 3.5 pF (Max) @ $V_{CB}$ = 30 Vdc
- Low Noise Figure — NF = 2.7 dB (Typ) @ $I_C$ = 10 mAdc






| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

### MAXIMUM RATINGS

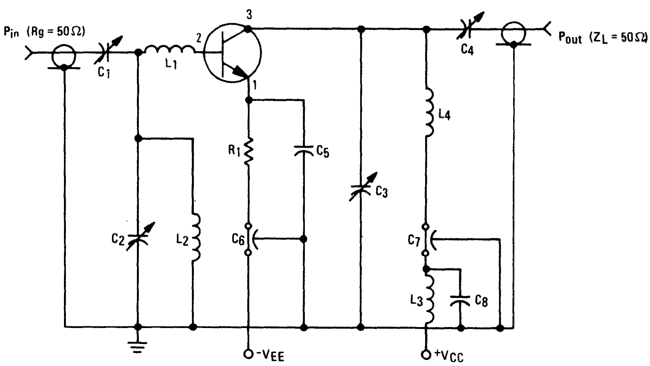
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 30 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 40 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.5 | Vdc |
| Collector Current | $I_C$ | 0.4 | Adc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 3.5<br>20 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J$, $T_{stg}$ | -65 to +200 | °C |

This is advance information and specifications are subject to change without notice.

## ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Sustaining Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO(sus)}$ | 30 | - | - | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 40 | - | - | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | - | - | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 28 Vdc, $I_B$ = 0) | $I_{CEO}$ | - | - | 20 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc) | $h_{FE}$ | 30 | - | - | - |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain–Bandwidth Product | $f_T$ | | | | MHz |
| ($I_C$ = 25 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) MM8000 | | 550 | - | - | |
| MM8001 | | 700 | - | - | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) MM8000 | | 700 | - | - | |
| MM8001 | | 900 | - | - | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) MM8000 | | 700 | - | - | |
| MM8001 | | 900 | - | - | |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | - | - | 3.5 | pF |
| Noise Figure Figure 1 ($I_C$ = 10 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | NF | - | 2.7 | - | dB |
| **FUNCTIONAL TESTS** | | | | | |
| Common-Emitter Amplifier Power Gain Figure 1 ($I_C$ = 10 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $G_{pe}$ | - | 11.4 | - | dB |

FIGURE 1 — 200 MHz TEST CIRCUIT




$C_1, C_2, C_3$: 1.0 – 30 pF
$C_4$: 1.0 – 20 pF
$C_5$: 10,000 pF
$C_6, C_7$: 1000 pF
$C_8$: 0.01 μF

$L_1$: 4-1/2 turns, No. 22 AWG wire, 3/16" I.D.
$L_4$: 3-1/2 turns, No. 22 AWG wire, 3/16" I.D.
$L_2, L_3$: 0.82 μH RFC
$R_1$: 240 ohms, 2 watts

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# MM8009

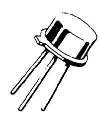
## The RF Line

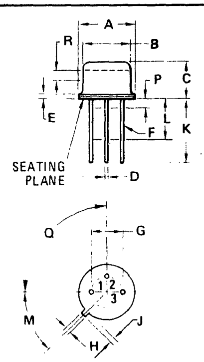
### NPN SILICON RF POWER TRANSISTOR

. . . designed for amplifier, frequency multiplier, or oscillator applications in military and industrial equipment. Suitable for use as output, driver, or pre-driver stages in UHF equipment and as a fundamental frequency oscillator at 1.68 GHz.

- High Output Power — $P_{out}$ = 0.9 Watt (Min) @ f = 1.0 GHz
- High Current-Gain—Bandwidth Product — $f_T$ = 1000 MHz (Min) @ $I_C$ = 50 mAdc
- Ideal for Radiosonde Applications — $P_{out}$ (Oscillator) = 300 mW (Typ) @ f = 1.68 GHz

0.9 W — 1.0 GHz
RF POWER
TRANSISTOR
NPN SILICON






STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 35 | Vdc |
| Collector-Base Voltage | $V_{CB}$ | 45 | Vdc |
| Emitter-Base Voltage | $V_{EB}$ | 3.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 400 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 1.0<br>5.71 | Watt<br>mW/°C |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 3.5<br>20 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J, T_{stg}$ | -65 to +200 | °C |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 45 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 100 | μAdc |
| Collector Cutoff Current ($V_{CE}$ = 35 Vdc, $V_{BE}$ = 0) | $I_{CES}$ | – | – | 10 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 20 | – | – | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain–Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 15 Vdc, f = 100 MHz) | $f_T$ | 1000 | – | – | MHz |
| Output Capacitance ($V_{CB}$ = 30 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 2.3 | 3.0 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Power Output (Figure 1) ($P_{in}$ = 316 mW, $V_{CE}$ = 28 Vdc, f = 1.0 GHz) | $P_{out}$ | 0.9 | – | – | Watt |
| Power Output (Oscillator) (Figure 2) ($V_{CE}$ = 20 Vdc, $V_{EB}$ = 1.5 Vdc, f = 1.68 GHz) (Minimum Efficiency = 15%) | $P_{out}$ | – | 0.3 | – | Watt |
| Collector Efficiency ($P_{in}$ = 316 mW, $V_{CE}$ = 28 Vdc, f = 1.0 GHz) | $\eta$ | 35 | – | – | % |

**FIGURE 1 – 1.0 GHz POWER AMPLIFIER TEST CIRCUIT**

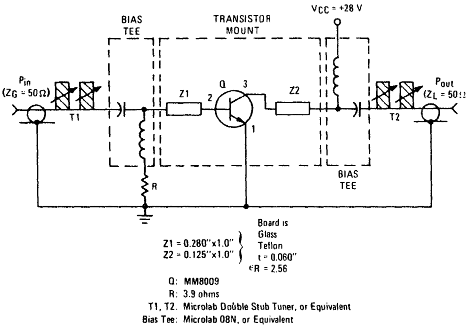



**FIGURE 2 – 1.68 GHz POWER OSCILLATOR TEST CIRCUIT**

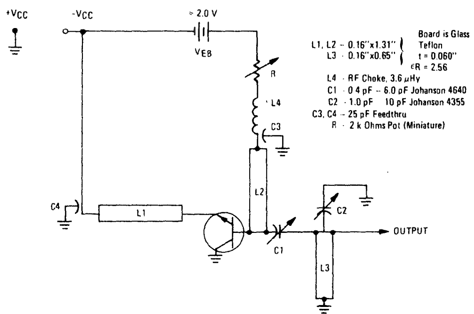


FIGURE 3 — POWER OUTPUT versus POWER INPUT

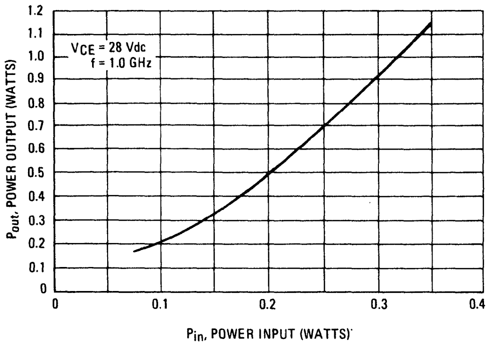



FIGURE 4 — POWER OUTPUT versus FREQUENCY

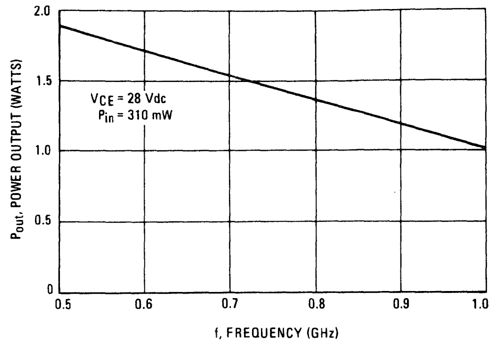



FIGURE 5 — POWER OUTPUT versus VOLTAGE

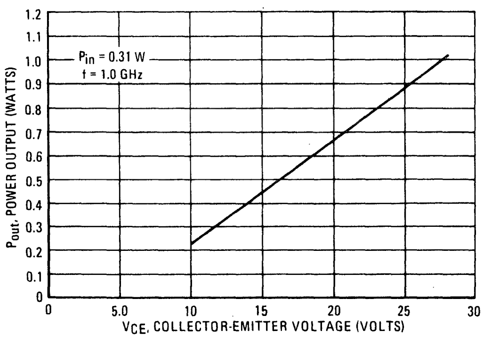



FIGURE 6 — OSCILLATOR POWER OUTPUT versus CURRENT

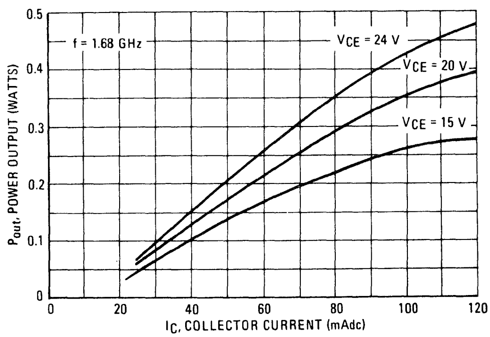



FIGURE 7 — CURRENT-GAIN—BANDWIDTH PRODUCT

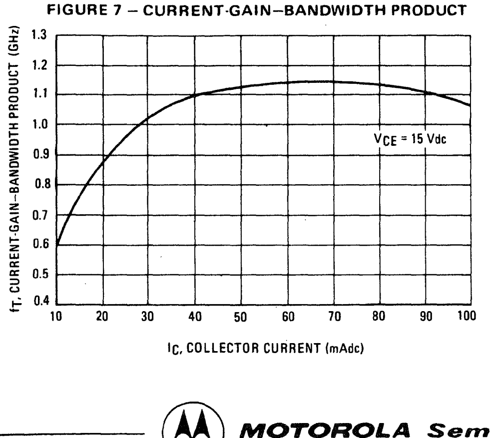
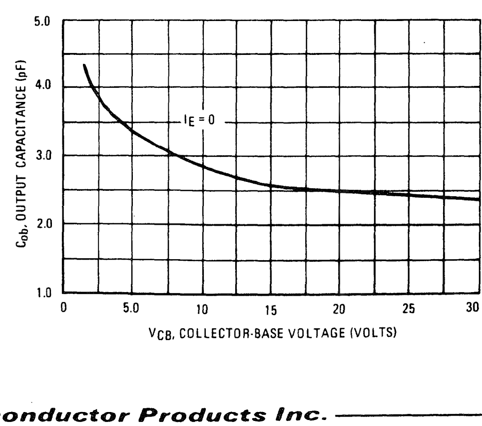



FIGURE 8 — OUTPUT CAPACITANCE versus VOLTAGE



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# MRF501
# MRF502

## The RF Line

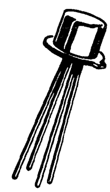
### NPN SILICON HIGH-FREQUENCY TRANSISTORS

. . . designed primarily for use in high-gain, low-noise amplifier, oscillator, and mixer applications. Can also be used in UHF converter applications.

- High Current-Gain – Bandwidth Product – $f_T$ = 1.2 GHz (Typ) @ $I_C$ = 5.0 mAdc
- Low Noise Figure – NF = 4.0 dB (Typ) @ f = 200 MHz

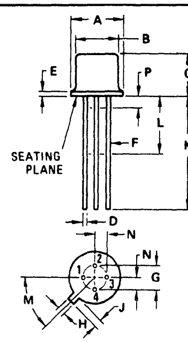
HIGH FREQUENCY TRANSISTORS

NPN SILICON



### MAXIMUM RATINGS

| Rating | Symbol | MRF501 | MRF502 | Unit |
|---|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 25 | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | | Vdc |
| Collector Current | $I_C$ | 50 | | mAdc |
| Total Device Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 200<br>1.14 | | mW<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | | $^oC$ |




STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

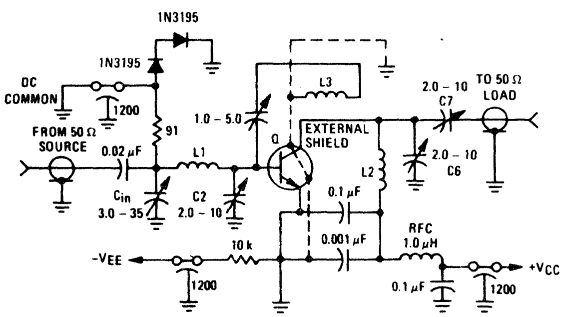
| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply
CASE 20-03
TO-72

ELECTRICAL CHARACTERISTICS ($T_A = 25^oC$ unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C = 3.0$ mAdc, $I_B = 0$) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C = 1.0\ \mu$Adc, $I_E = 0$) MRF501 / MRF502 | $BV_{CBO}$ | 25 / 35 | – / – | – / – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E = 1.0\ \mu$Adc, $I_C = 0$) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB} = 1.0$ Vdc, $I_E = 0$) MRF501 / MRF502 | $I_{CBO}$ | – / – | – / – | 50 / 20 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C = 1.0$ mAdc, $V_{CE} = 6.0$ Vdc) MRF501 / MRF502 | $h_{FE}$ | 30 / 40 | – / – | 250 / 170 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current Gain – Bandwdith Product ($I_C = 5.0$ mAdc, $V_{CE} = 6.0$ Vdc, f = 100 MHz) MRF501 / MRF502 | $f_T$ | 600 / 800 | 1000 / 1200 | – / – | MHz |
| Collector-Base Capacitance ($V_{CB} = 10$ Vdc, $I_E = 0$, f = 0.1 to 1.0 MHz) | $C_{cb}$ | – | 0.6 | – | pF |
| Collector-Base Time Constant ($I_E = 2.0$ mAdc, $V_{CB} = 6.0$ Vdc, f = 31.8 MHz) | $r_b'C_c$ | – | 8.0 | – | ps |
| Noise Figure (Figure 1) ($I_C = 1.5$ mAdc, $V_{CE} = 6.0$ Vdc, $R_S = 50$ ohms, f = 200 MHz) MRF501 / MRF502 | NF | – / – | 4.5 / 4.0 | – / – | dB |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain (Figure 1) ($V_{CC} = 6.0$ Vdc, $I_C = 5.0$ mAdc, f = 200 MHz) MRF501 / MRF502 | $G_{pe}$ | – / – | 15 / 17 | – / – | dB |

FIGURE 1 – 200 MHz AMPLIFIER POWER GAIN AND NOISE FIGURE CIRCUIT




L1 1 3/4 Turns, #18 AWG, 0.5" Long, 0.5" Diameter
L2 2 Turns, #16 AWG, 0.5" Long, 0.5" Diameter
L3 2 Turns, #18 AWG, 0.25" Long, 0.5" Diameter, Position Approximately 0.25" from L2

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# MRF511

## The RF Line

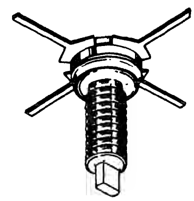
### NPN SILICON HIGH FREQUENCY TRANSISTOR

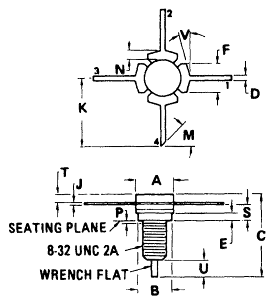
. . . designed specifically for broadband applications requiring low distortion characteristics and noise figure. Specified for use in CATV applications.

- Specified +50 dBmV Output, 80 mAdc Distortion Characteristics –
  Triple Beat = -65 dB (Max)
  Cross Modulation = -57 dB (Max)
  Second Order = -50 dB (Max)
- High Broadband Power Gain –
  $G_{pe}$ = 10 dB (Min) @ f = 250 MHz
- Low Broadband Noise Figure –
  NF = 10 dB (Max) @ f = 200 MHz

HIGH FREQUENCY TRANSISTOR

NPN SILICON






STYLE 1:
PIN 1. EMITTER
2. BASE
3. EMITTER
4. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 7.06 | 7.26 | 0.278 | 0.286 |
| B | 6.20 | 6.50 | 0.244 | 0.256 |
| C | 14.99 | 16.89 | 0.590 | 0.665 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 1.50 | – | 0.059 | – |
| F | 5.46 | 5.97 | 0.215 | 0.235 |
| J | 0.08 | 0.18 | 0.003 | 0.007 |
| K | 12.45 | – | 0.490 | – |
| M | 45° NOM | | 45° NOM | |
| N | 1.40 | 1.65 | 0.055 | 0.065 |
| P | – | 1.27 | – | 0.050 |
| S | 3.00 | 3.25 | 0.118 | 0.128 |
| T | 1.40 | 1.78 | 0.055 | 0.070 |
| U | 2.92 | 3.68 | 0.115 | 0.145 |
| V | 10° | 20° | 10° | 20° |

CASE 144D-06

### MAXIMUM RATINGS

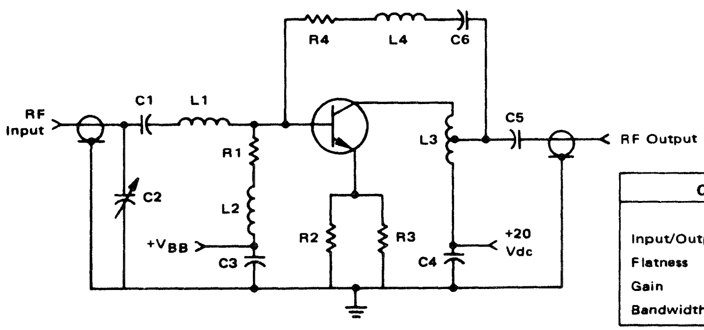
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 250 | mAdc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 5.0<br>28.6 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |
| Stud Torque(1) | – | 6.5 | In. Lb. |

(1) For Repeated Assembly use 5 In. Lb.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristics | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 100 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 80 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 25 | 50 | 200 | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 100 mAdc, $I_B$ = 10 mAdc) | $V_{CE(sat)}$ | – | 0.2 | 0.5 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain—Bandwidth Product ($I_C$ = 80 mAdc, $V_{CE}$ = 20 Vdc, f = 200 MHz) | $f_T$ | 1.5 | 2.1 | – | GHz |
| Output Capacitance ($V_{CB}$ = 20 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.2 | 4.5 | pF |
| Noise Figure ($I_C$ = 50 mAdc, $V_{CE}$ = 20 Vdc, f = 200 MHz) | NF | – | 7.3 | 10 | dB |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CE}$ = 20 Vdc, $I_C$ = 80 mAdc, f = 250 MHz) | $G_{pe}$ | 10 | 11 | – | dB |
| 2nd Order Intermodulation Distortion ($V_{CE}$ = 20 Vdc, $I_C$ = 80 mAdc, $V_{out}$ = +50 dBmV, Chn 2 + Chn 13 = 266.5 MHz) | IMD | – | -55 | -50 | dB |
| Cross-Modulation Distortion ($V_{CE}$ = 20 Vdc, $V_{out}$ = +50 dBmV, $I_C$ = 80 mAdc) Chn 13<br>Chn R | 12 Chn XMD<br>30 Chn XMD | –<br>– | -59<br>-46 | -57<br>– | dB |
| Triple Beat ($V_{CE}$ = 20 Vdc, $I_C$ = 80 mAdc, $V_{out}$ = +50 dBmV, Chn 2 + Chn 3 + Chn E = 261.75 MHz) | TB | – | -68 | -65 | dB |

**FIGURE 1 — 40 to 330 MHz BROADBAND TEST CIRCUIT SCHEMATIC**




| CIRCUIT PERFORMANCE | Min | Typ |
|---|---|---|
| Input/Output Return Loss | – | 18 dB |
| Flatness | – | +0.3 dB |
| Gain | 10 dB | |
| Bandwidth | – | 40-300 MHz |

| | |
|---|---|
| C1,C3,C4,C5,C6 | 0.002 μF Ceramic Disc |
| C2 | 0.35-3.5 pF JOHANSON 4702 |
| L1 | 2 Turns, #20 AWG, 1/8" I.D., 0.2" Long |
| L2 | 5 μH, Ferrite Choke, MILLER |
| L3 | 18 Turns, #24 AWG Enamelled, on Ferrite Torrid Core FERROXCUBE 1041TO60-4C7 |
| L4 | 5 Turns, #20 AWG, 3/16" I.D., 0.35" Long |
| R1 | 4.7 kΩ, 1/4W, 10% |
| R2 | 27 Ω, 1W, 10% |
| R3 | 27 Ω, 1W, 10% |
| R4 | 300 Ω, 1/4W, 10%. |

Input/Output Connectors — Type F

$Z_o$ — 75 Ohms

FIGURE 2 – CURRENT-GAIN–BANDWIDTH PRODUCT

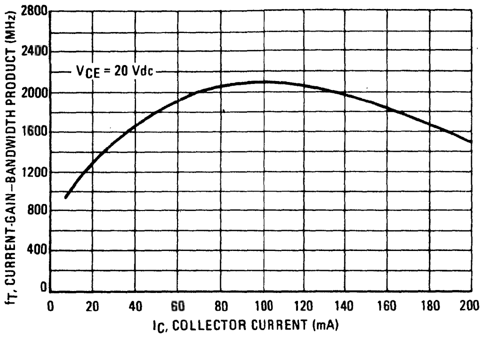



FIGURE 3 – OUTPUT CAPACITANCE

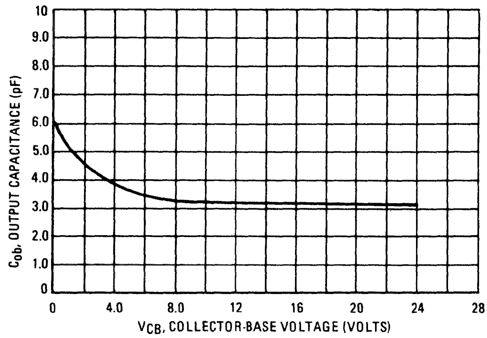



FIGURE 4 – INPUT CAPACITANCE

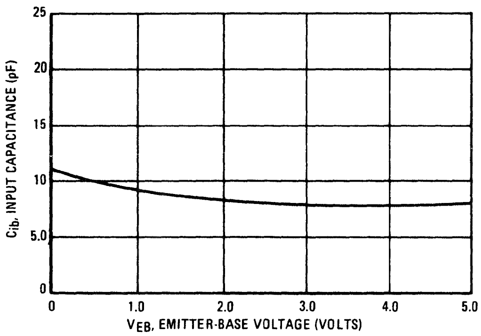



FIGURE 5 – BROADBAND NOISE FIGURE

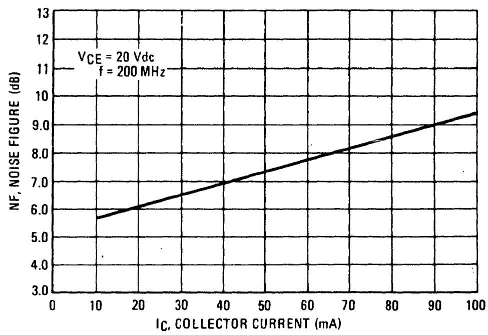



FIGURE 6 – 12 CHANNEL CROSS-MODULATION
versus COLLECTOR-EMITTER VOLTAGE

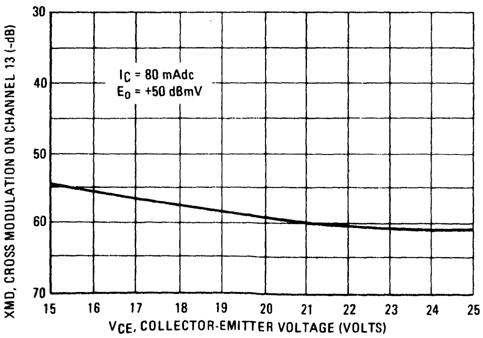



FIGURE 7 – 12 CHANNEL CROSS-MODULATION
versus COLLECTOR CURRENT

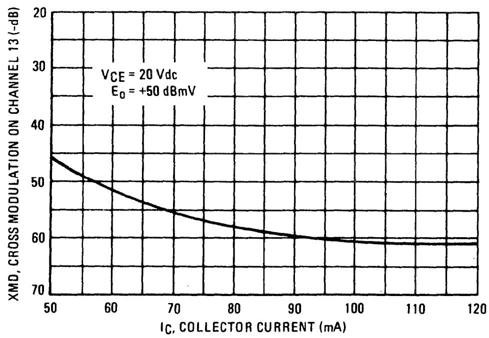


FIGURE 8 – 30 CHANNEL CROSS-MODULATION ON CHANNEL R

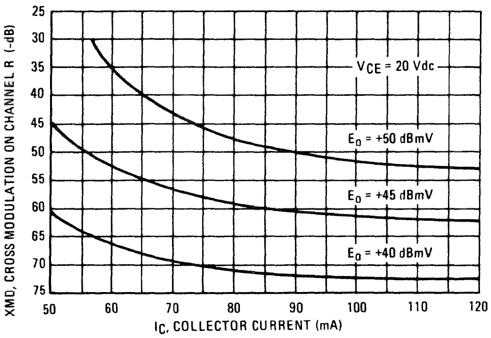



FIGURE 9 – 30 CHANNEL CROSS-MODULATION ON CHANNEL 2,13,R

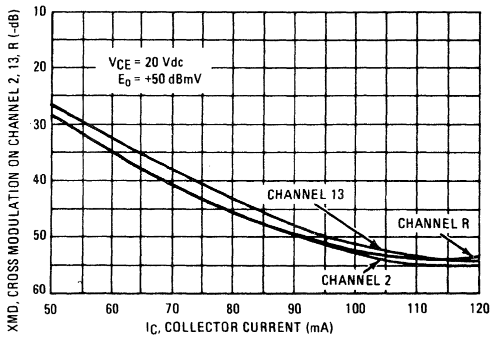



FIGURE 10 – 30-CHANNEL CROSS-MODULATION versus COLLECTOR-EMITTER VOLTAGE

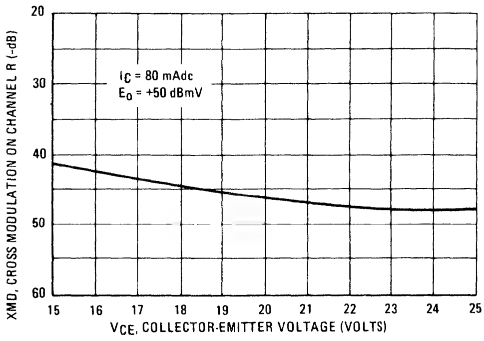



FIGURE 11 – TRIPLE BEAT versus COLLECTOR CURRENT

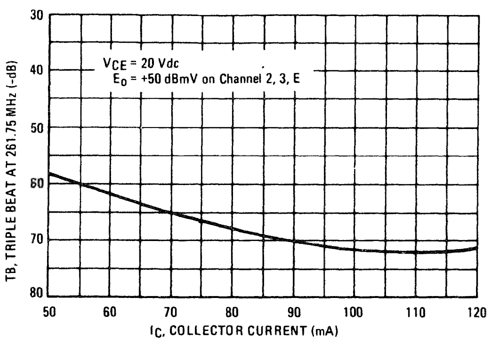



FIGURE 12 – TRIPLE BEAT versus COLLECTOR-EMITTER VOLTAGE

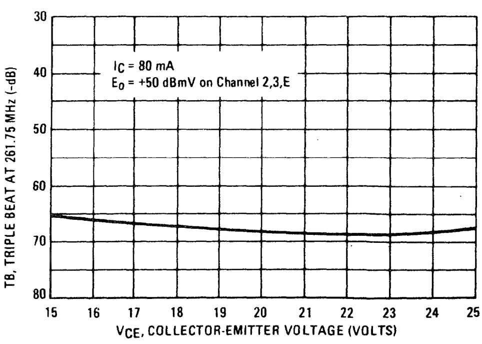


FIGURE 13 – SECOND ORDER IMD versus COLLECTOR CURRENT

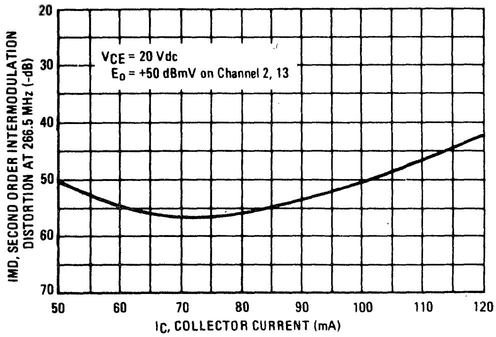



FIGURE 14 – SECOND ORDER IMD versus COLLECTOR-EMITTER VOLTAGE

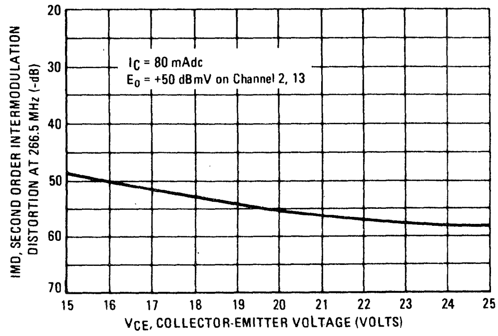



FIGURE 15 – INPUT REFLECTION COEFFICIENT (S11) AND OUTPUT REFLECTION COEFFICIENT (S22) versus FREQUENCY

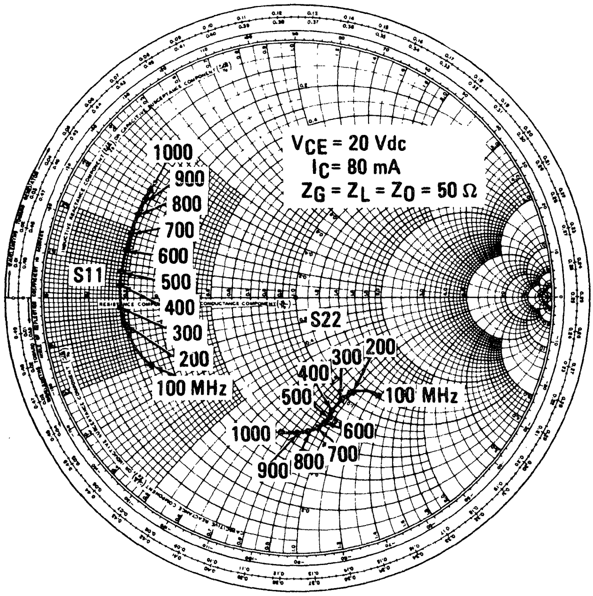


FIGURE 16 – FORWARD TRANSMISSION COEFFICIENT (S21) versus FREQUENCY

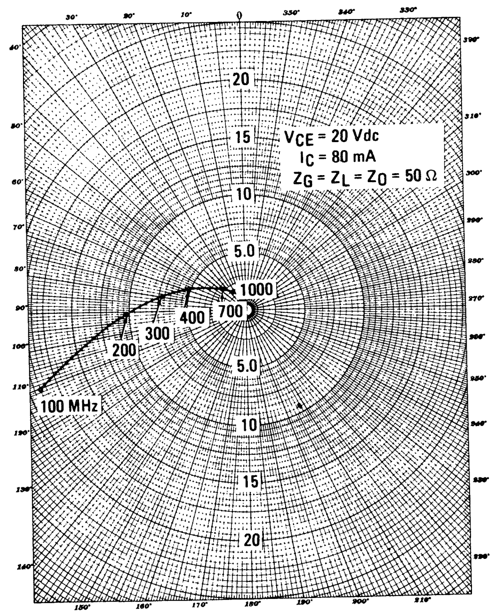
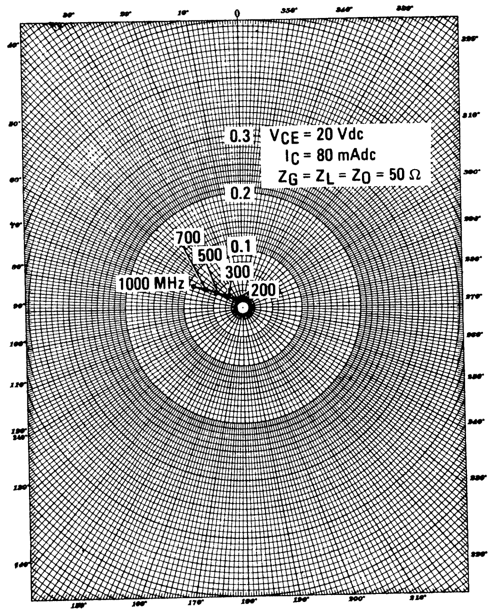



FIGURE 17 – REVERSE TRANSMISSION COEFFICIENT (S12) versus FREQUENCY



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# MRF517

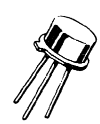
## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed specifically for broadband applications requiring low distortion characteristics. Specified for use in CATV distribution equipment.

- Specified +45 dBmV Output, 60 mA Distortion Characteristics –
  Triple Beat = -72 dB (Max)
  12 Channel Cross Modulation = -57 dB (Max)
  Second Order = -60 dB (Max)
- Broadband Power Gain –
  $G_{PE}$ = 10 dB (Typ)
- Broadband Noise Figure –
  NF = 7.5 dB (Max) @ f = 300 MHz

**HIGH FREQUENCY TRANSISTOR**
**NPN SILICON**



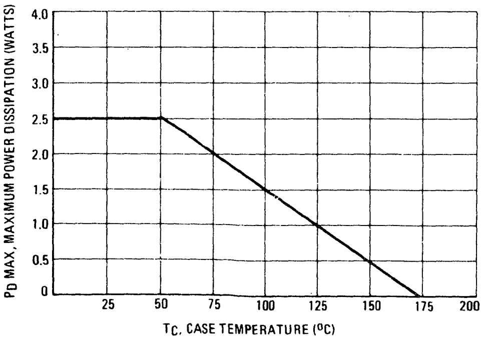
### MAXIMUM RATINGS

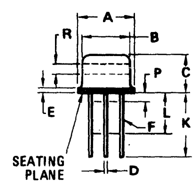
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage ($R_{BE}$ = 330 Ω) | $V_{CER}$ | 25 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 150 | mAdc |
| Total Power Dissipation @ $T_C$ = 50°C<br>Derate above 50°C | $P_D$ | 2.5<br>0.02 | Watts<br>W/°C |
| Operating Junction Temperature | $T_J$ | +175 | °C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

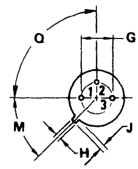
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 50 | °C/W |

FIGURE 1 – POWER DISSIPATION




STYLE 1
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

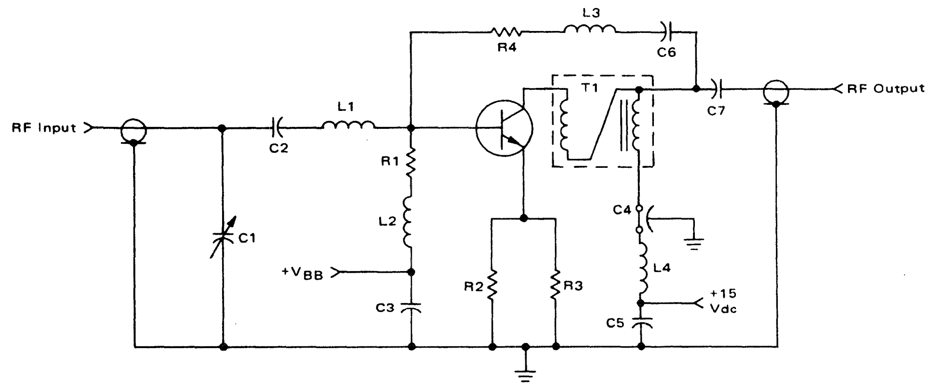
All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | – | – | Vdc |
| Collector-Emitter Breakdown Voltage ($I_C$ = 5.0 mAdc, $R_{BE}$ = 330 Ohms) | $BV_{CER}$ | 25 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 100 μAdc, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 100 μAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 15 Vdc, $I_B$ = 0) | $I_{CEO}$ | – | – | 100 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 60 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 50 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 60 mAdc, $V_{CE}$ = 15 Vdc, f = 200 MHz) | $f_T$ | 2200 | 2700 | – | MHz |
| Output Capacitance ($V_{CB}$ = 15 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | 4.5 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CE}$ = 15 Vdc, $I_C$ = 60 mAdc, f = 300 MHz) | $G_{pe}$ | – | 10 | – | dB |
| Broadband Noise Figure ($V_{CE}$ = 15 Vdc, $I_C$ = 50 mAdc, f = 300 MHz) | NF | – | – | 7.5 | dB |
| 2nd Order Distortion ($V_{CE}$ = 15 Vdc, $I_C$ = 60 mAdc, $E_{out}$ = +45 dBmV, Ch 2 + Ch G = 212.5 MHz) | $IMD_2$ | – | – | -60 | dB |
| NCTA Cross Modulation Distortion, 12 Ch's (2-13) ($V_{CE}$ = 15 Vdc, $I_C$ = 60 mAdc, $E_{out}$ = +45 dBmV, Measured at Ch's 2 and 13) | $XMD_{12}$ | – | – | -57 | dB |
| Triple Beat Distortion, 3 Ch's ($V_{CE}$ = 15 Vdc, $I_C$ = 60 mAdc, $E_{out}$ = +45 dBmV, Ch's (4 + 5 + A) = 265 MHz) | $TB_3$ | – | – | -72 | dB |

**FIGURE 2 – 40 to 330 MHz BROADBAND TEST CIRCUIT SCHEMATIC**




| | | | |
|---|---|---|---|
| C1 | 1.0 – 10 pF JOHANSON | L4 | VK200 |
| C2,C6,C7 | 0.002 μF Ceramic Disk | T1 | 16:1 Bifilar Wound, #20 AWG Enameled Wire, Wound on a FERROXCUBE 1041T060-4C4 Core |
| C3,C5 | 0.1 μF, 50 Vdc Tantalum | | |
| C4 | 1000 pF Button | R1 | 4.7 kΩ, 1/4 Watt, 10% |
| L1 | 1 Turn, #20 AWG | R2,R3 | 27 Ω, 1/4 Watt, 5% |
| L2 | 5.6 μH Molded Choke | R4 | 270 Ω, 1/4 Watt, 5% |
| L3 | 4 Turns, #20 AWG, 1/4" I.D. | | |

Input/Output Connectors – Type F
$Z_o$ = 75 Ohms

**FIGURE 3 — TYPICAL RESPONSE CURVE**
(See Figure 2)

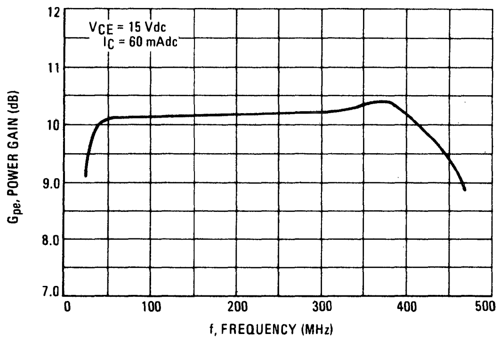



**FIGURE 4 — COMMON-EMITTER POWER GAIN versus FREQUENCY**

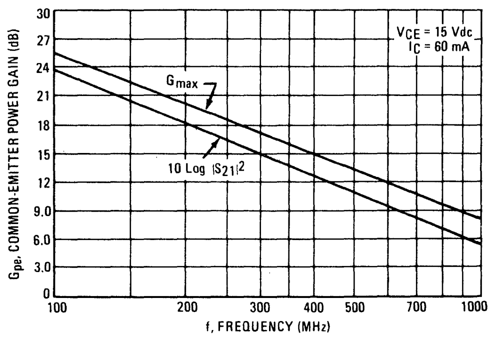



**FIGURE 5 — CURRENT GAIN BANDWIDTH PRODUCT versus COLLECTOR CURRENT**

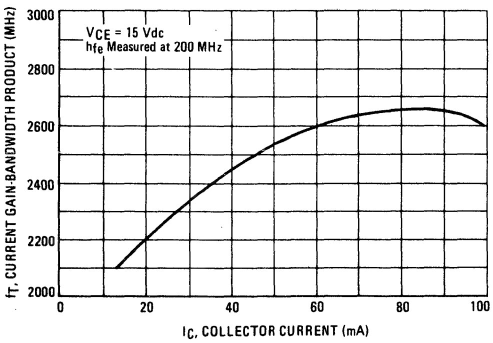



**FIGURE 6 — INPUT CAPACITANCE versus EMITTER-BASE VOLTAGE**

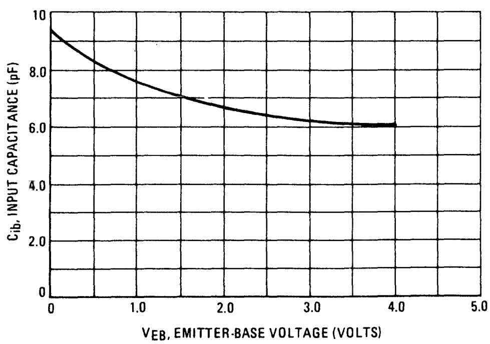



**FIGURE 7 — OUTPUT CAPACITANCE versus COLLECTOR-BASE VOLTAGE**

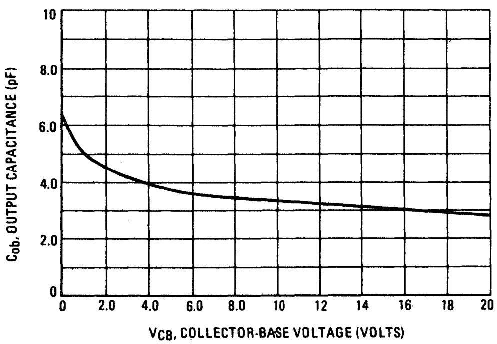



**FIGURE 8 — BROADBAND NOISE FIGURE versus COLLECTOR CURRENT**

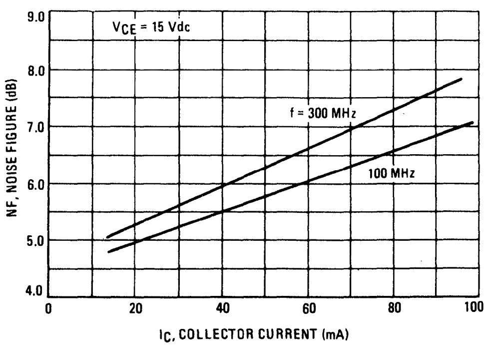


FIGURE 9 — 2nd ORDER DISTORTION ($f_1 \pm f_2$) versus COLLECTOR CURRENT

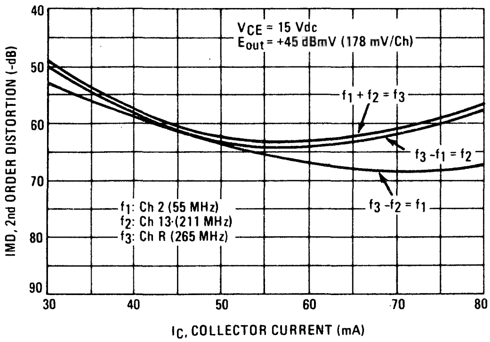



FIGURE 10 — 12-CHANNEL CROSS MODULATION DISTORTION versus COLLECTOR CURRENT

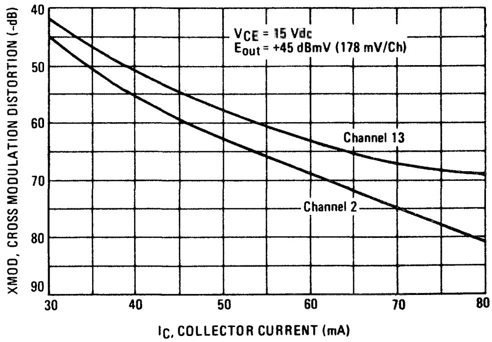



FIGURE 11 — DIN 45004 CROSS-MODULATION DISTORTION

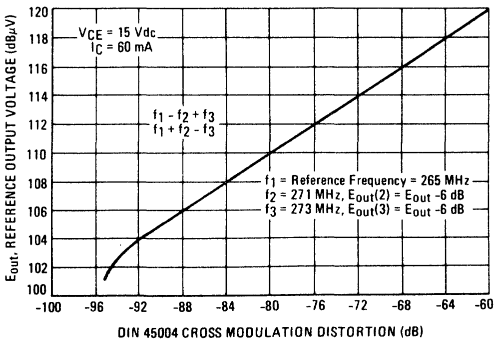



FIGURE 12 — TRIPLE BEAT DISTORTION ($f_1 + f_2 + f_3$) versus COLLECTOR CURRENT

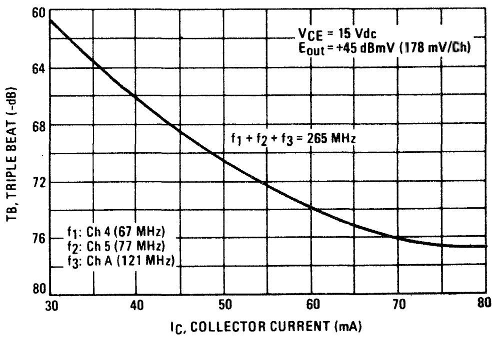
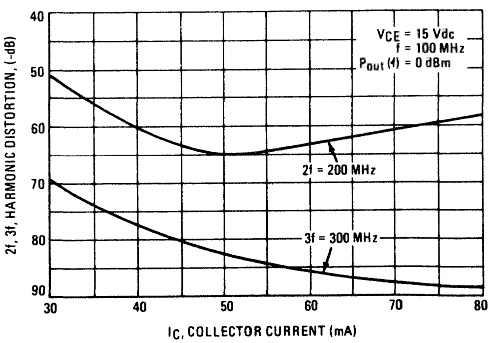



FIGURE 13 — HARMONIC DISTORTION (2f, 3f) versus COLLECTOR CURRENT



| $V_{CE}$ (Volts) | $I_C$ (mA) | Frequency (MHz) | S11 |S11| | S11 ∠φ | S21 |S21| | S21 ∠φ | S12 |S12| | S12 ∠φ | S22 |S22| | S22 ∠φ |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 30 | 100 | 0.538 | -152 | 12.821 | 100 | 0.043 | 49 | 0.381 | -102 |
| | | 200 | 0.546 | -173 | 6.612 | 86 | 0.064 | 55 | 0.314 | -121 |
| | | 400 | 0.557 | 163 | 3.440 | 71 | 0.105 | 60 | 0.315 | -132 |
| | | 600 | 0.602 | 147 | 2.357 | 59 | 0.144 | 61 | 0.360 | -140 |
| | | 800 | 0.625 | 136 | 1.872 | 46 | 0.181 | 59 | 0.437 | -143 |
| | | 1000 | 0.626 | 120 | 1.614 | 34 | 0.211 | 57 | 0.482 | -144 |
| | 60 | 100 | 0.532 | -160 | 13.475 | 98 | 0.040 | 54 | 0.362 | -111 |
| | | 200 | 0.542 | -178 | 6.850 | 86 | 0.063 | 60 | 0.314 | -130 |
| | | 400 | 0.558 | 160 | 3.586 | 72 | 0.109 | 63 | 0.313 | -140 |
| | | 600 | 0.602 | 145 | 2.475 | 60 | 0.151 | 62 | 0.353 | -146 |
| | | 800 | 0.619 | 134 | 1.962 | 48 | 0.190 | 59 | 0.423 | -147 |
| | | 1000 | 0.616 | 118 | 1.706 | 35 | 0.221 | 57 | 0.464 | -147 |
| | 90 | 100 | 0.532 | -163 | 13.530 | 98 | 0.038 | 57 | 0.354 | -115 |
| | | 200 | 0.545 | 179 | 6.908 | 85 | 0.063 | 62 | 0.313 | -133 |
| | | 400 | 0.558 | 159 | 3.607 | 72 | 0.111 | 64 | 0.312 | -143 |
| | | 600 | 0.604 | 145 | 2.489 | 61 | 0.153 | 63 | 0.352 | -148 |
| | | 800 | 0.620 | 133 | 1.982 | 48 | 0.193 | 59 | 0.419 | -149 |
| | | 1000 | 0.614 | 117 | 1.721 | 35 | 0.224 | 57 | 0.455 | -148 |
| 10 | 30 | 100 | 0.500 | -145 | 14.176 | 102 | 0.040 | 50 | 0.386 | -87 |
| | | 200 | 0.502 | -170 | 7.358 | 87 | 0.059 | 55 | 0.304 | -105 |
| | | 400 | 0.512 | 164 | 3.819 | 71 | 0.097 | 61 | 0.304 | -118 |
| | | 600 | 0.559 | 149 | 2.593 | 59 | 0.133 | 62 | 0.356 | -128 |
| | | 800 | 0.583 | 137 | 2.033 | 46 | 0.166 | 60 | 0.442 | -134 |
| | | 1000 | 0.584 | 122 | 1.724 | 34 | 0.194 | 59 | 0.497 | -137 |
| | 60 | 100 | 0.487 | -154 | 14.977 | 100 | 0.037 | 55 | 0.353 | -96 |
| | | 200 | 0.498 | -174 | 7.715 | 86 | 0.059 | 60 | 0.287 | -114 |
| | | 400 | 0.506 | 161 | 4.009 | 72 | 0.101 | 63 | 0.294 | -125 |
| | | 600 | 0.553 | 146 | 2.731 | 60 | 0.139 | 63 | 0.341 | -133 |
| | | 800 | 0.572 | 135 | 2.158 | 47 | 0.174 | 60 | 0.422 | -137 |
| | | 1000 | 0.569 | 119 | 1.835 | 35 | 0.202 | 58 | 0.475 | -139 |
| | 90 | 100 | 0.486 | -157 | 15.192 | 99 | 0.036 | 57 | 0.337 | -98 |
| | | 200 | 0.493 | -176 | 7.764 | 86 | 0.058 | 61 | 0.280 | -116 |
| | | 400 | 0.508 | 160 | 4.043 | 72 | 0.101 | 64 | 0.287 | -126 |
| | | 600 | 0.555 | 145 | 2.761 | 60 | 0.141 | 63 | 0.336 | -134 |
| | | 800 | 0.574 | 134 | 2.184 | 47 | 0.176 | 60 | 0.417 | -138 |
| | | 1000 | 0.568 | 118 | 1.861 | 35 | 0.204 | 58 | 0.469 | -139 |
| 15 | 30 | 100 | 0.465 | -153 | 15.774 | 100 | 0.035 | 56 | 0.337 | -88 |
| | | 200 | 0.475 | -174 | 8.091 | 86 | 0.056 | 61 | 0.274 | -105 |
| | | 400 | 0.487 | 161 | 4.209 | 71 | 0.097 | 64 | 0.284 | -116 |
| | | 600 | 0.532 | 146 | 2.863 | 59 | 0.133 | 63 | 0.337 | -126 |
| | | 800 | 0.551 | 135 | 2.249 | 47 | 0.167 | 60 | 0.425 | -132 |
| | | 1000 | 0.547 | 119 | 1.909 | 34 | 0.193 | 58 | 0.482 | -135 |
| | 60 | 100 | 0.468 | -150 | 15.650 | 101 | 0.036 | 54 | 0.354 | -87 |
| | | 200 | 0.475 | -172 | 8.088 | 87 | 0.057 | 60 | 0.282 | -104 |
| | | 400 | 0.486 | 163 | 4.178 | 72 | 0.096 | 63 | 0.290 | -116 |
| | | 600 | 0.530 | 147 | 2.846 | 60 | 0.133 | 63 | 0.341 | -126 |
| | | 800 | 0.549 | 136 | 2.228 | 47 | 0.166 | 60 | 0.429 | -132 |
| | | 1000 | 0.547 | 120 | 1.887 | 34 | 0.192 | 59 | 0.487 | -135 |
| | 90 | 100 | 0.487 | -141 | 14.773 | 103 | 0.039 | 50 | 0.391 | -80 |
| | | 200 | 0.486 | -167 | 7.724 | 87 | 0.057 | 55 | 0.303 | -97 |
| | | 400 | 0.491 | 166 | 3.986 | 71 | 0.093 | 61 | 0.306 | -110 |
| | | 600 | 0.537 | 150 | 2.694 | 59 | 0.127 | 62 | 0.359 | -122 |
| | | 800 | 0.565 | 138 | 2.108 | 45 | 0.159 | 60 | 0.448 | -129 |
| | | 1000 | 0.566 | 123 | 1.779 | 33 | 0.185 | 60 | 0.507 | -134 |

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# MRF531

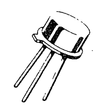
## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for high voltage and high current $f_T$ switching applications. These devices are also ideal for CRT drivers.

- High Collector-Emitter Breakdown Voltage — $BV_{CEO}$ = 100 Vdc (Min) @ $I_C$ = 10 mAdc
- High Current-Gain — Bandwidth Product — $f_T$ = 800 MHz (Typ) @ $I_C$ = 50 mAdc
- Characterized with Safe Operating Area (SOA) Curves

HIGH FREQUENCY TRANSISTOR
NPN SILICON



### MAXIMUM RATINGS

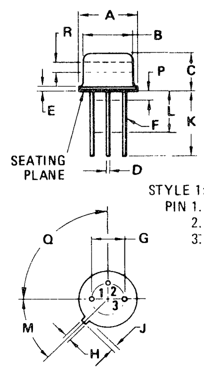
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 100 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 100 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 2.5<br>40 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 25 | °C/W |

### ELECTRICAL CHARACTERISTICS ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 100 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 100 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | – | – | Vdc |
| Collector Cutoff Current ($V_{CE}$ = 75 Vdc, $V_{BE}$ = 0) | $I_{CES}$ | – | – | 10 | μAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 25 | – | – | – |
| Collector-Emitter Saturation Voltage ($I_C$ = 10 mAdc, $I_B$ = 1.0 mAdc) | $V_{CE(sat)}$ | – | – | 1.0 | Vdc |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain — Bandwidth Product ($I_C$ = 50 mAdc, $V_{CE}$ = 25 Vdc, f = 100 MHz) | $f_T$ | 500 | 800 | – | MHz |
| Output Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | – | 4.0 | pF |
| Input Capacitance ($V_{BE}$ = 3.0 Vdc, $I_C$ = 0, f = 1.0 MHz) | $C_{ib}$ | – | 9.0 | – | pF |




STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 8.89 | 9.40 | 0.350 | 0.370 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 6.10 | 6.60 | 0.240 | 0.260 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | 0.229 | 3.18 | 0.009 | 0.125 |
| F | 0.406 | 0.483 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.711 | 0.864 | 0.028 | 0.034 |
| J | 0.737 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° NOM | | 45° NOM | |
| P | – | 1.27 | – | 0.050 |
| Q | 90° NOM | | 90° NOM | |
| R | 2.54 | – | 0.100 | – |

All JEDEC dimensions and notes apply.

CASE 79-02
TO-39

FIGURE 1 – CURRENT-GAIN – BANDWIDTH PRODUCT

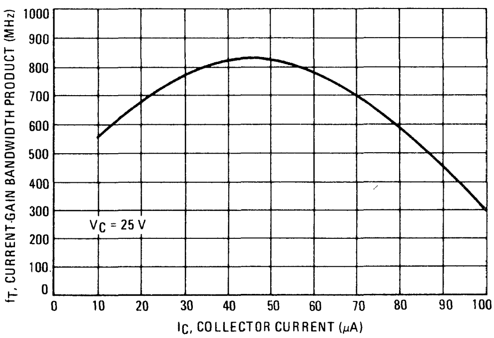



FIGURE 2 – INPUT CAPACITANCE

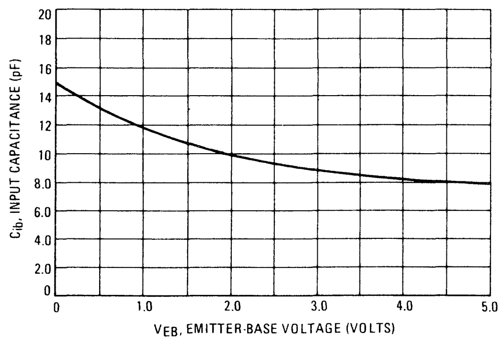



FIGURE 3 – OUTPUT CAPACITANCE

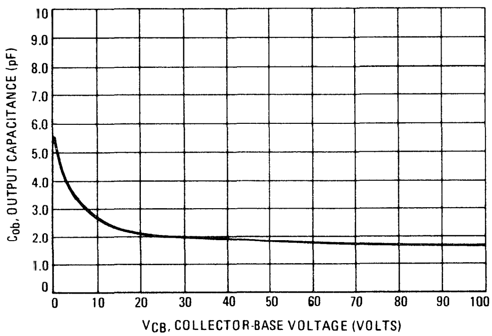
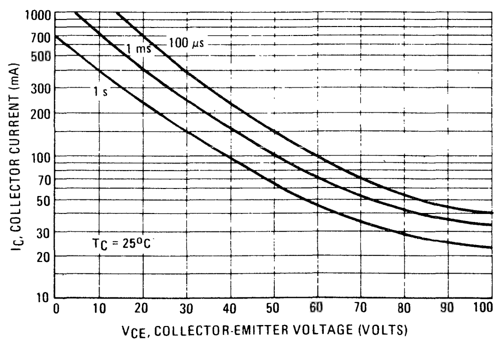



FIGURE 4 – DC SAFE OPERATING AREA



**MOTOROLA**
**Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF901

## The RF Line

### NPN SILICON HIGH-FREQUENCY TRANSISTOR

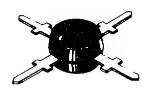
. . . designed primarily for use in high-gain, low-noise small-signal amplifiers. Also usable in applications requiring fast switching times.

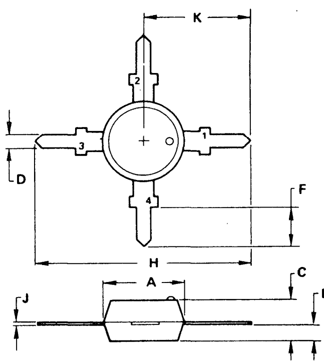
- High Current-Gain-Bandwidth Product — $f_T$ = 4.5 GHz (Typ) @ $I_C$ = 15 mAdc
- Low Noise Figure @ f = 1.0 GHz — NF = 2.0 dB (Typ) and 2.5 dB (Max)
- High Power Gain — $G_{pe}$ = 10 dB (Min) @ f = 1.0 GHz
- Third Order Intercept = +23 dBm (Typ)

**2.5 dB @ 1.0 GHz**

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**






STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | – | 4.78 | – | 0.188 |
| C | – | 3.05 | – | 0.120 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 0.97 | 1.22 | 0.038 | 0.048 |
| F | 2.21 | 2.46 | 0.087 | 0.097 |
| H | 12.40 | 12.90 | 0.488 | 0.508 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 6.20 | 6.45 | 0.244 | 0.254 |

CASE 302-01

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector – Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector – Base Voltage | $V_{CBO}$ | 25 | Vdc |
| Emitter – Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Continuous | $I_C$ | 30 | mAdc |
| Total Device Dissipation @$T_C$ = 25°C<br>Derate Above 25°C | $P_D$ | 0.375<br>3.3 | Watt<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | 150 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Ambient | $R_{\theta JA}$ | 300 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CEO}$ | 25 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 30 | 80 | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain-Bandwith Product ($I_C$ = 15 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | $f_T$ | – | 4.5 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.4 | 1.0 | pF |
| Noise Figure ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 1.0 GHz) | NF | – | 2.0 | 2.5 | dB |
| **FUNCTIONAL TESTS** (Figure 1) | | | | | |
| Common-Emitter Amplifier Power Gain ($V_{CC}$ = 6.0 Vdc, $I_C$ = 5.0 mA, f = 1.0 GHz) | $G_{pe}$ | 10 | 12 | – | dB |
| Third Order Intercept ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 0.9 GHz) | – | – | +23 | – | dBm |

**FIGURE 1 — 1.0 GHz TEST CIRCUIT SCHEMATIC**

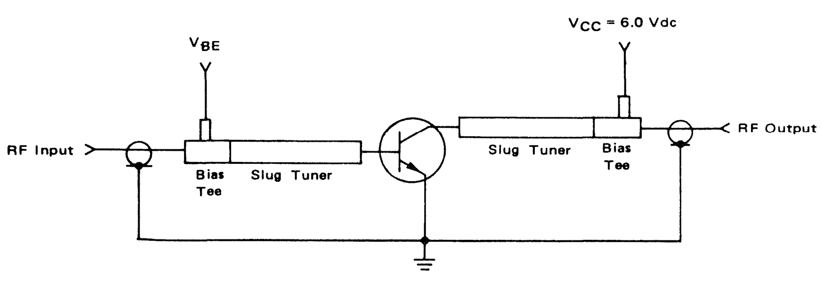


FIGURE 2 – CURRENT-GAIN – BANDWIDTH PRODUCT versus COLLECTOR CURRENT

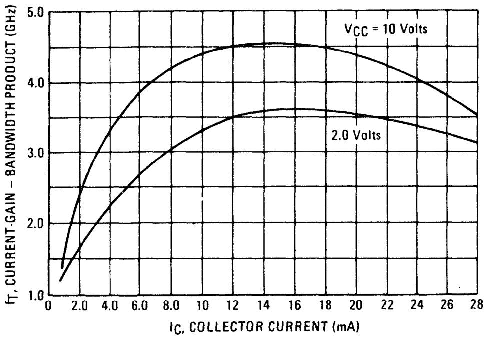



FIGURE 3 – NOISE FIGURE versus FREQUENCY

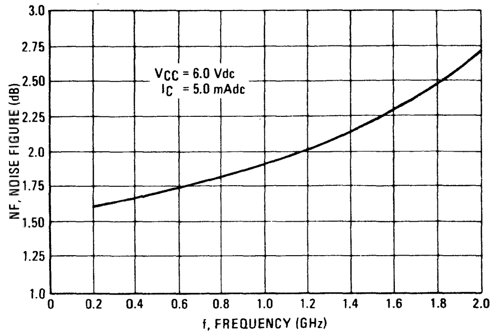



FIGURE 4 – NOISE FIGURE versus COLLECTOR CURRENT

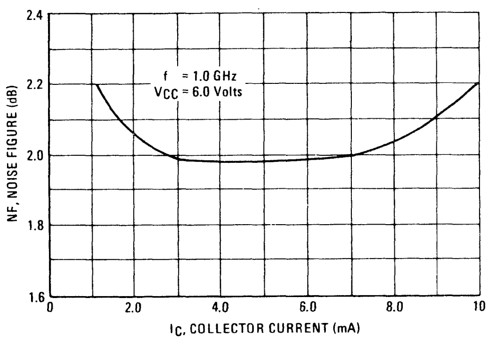



FIGURE 5 – OUTPUT POWER versus INPUT POWER

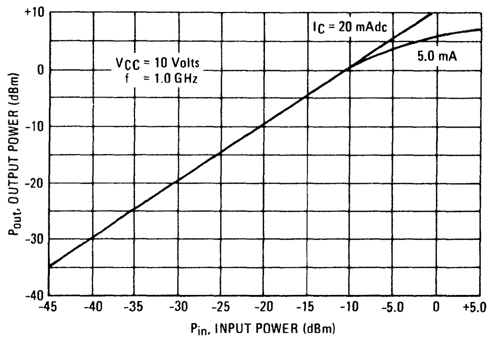



FIGURE 6 – $G_{max}$ versus FREQUENCY

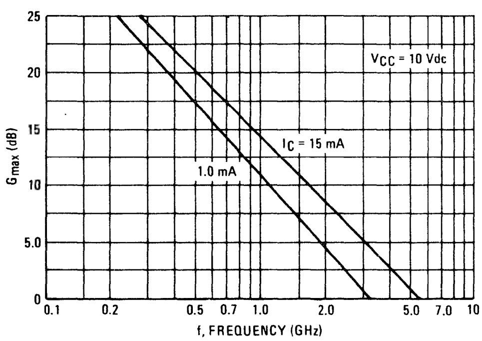



FIGURE 7 – COLLECTOR-BASE CAPACITANCE versus COLLECTOR-BASE VOLTAGE

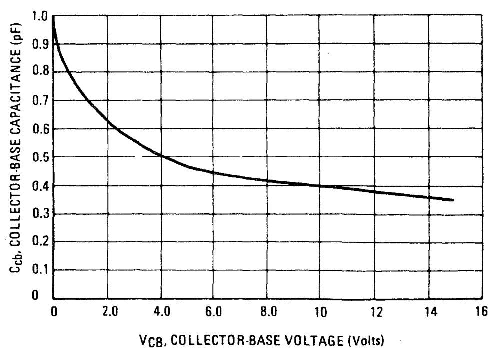


TABLE I – $S_{11}$

| FREQUENCY (MHz) | | 200 | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ | $I_C$ | $\|S_{11}\|$ | ∠φ | $\|S_{11}\|$ | ∠φ | $\|S_{11}\|$ | ∠φ | $\|S_{11}\|$ | ∠φ | $\|S_{11}\|$ | ∠φ |
| 1 Volt | 1.0mA | .83 | −54 | .65 | −110 | .61 | −153 | .62 | +177 | .65 | +157 |
| | 2.5 | .72 | −74 | .57 | −132 | .56 | −171 | .58 | +165 | .61 | +148 |
| | 5.0 | .63 | −98 | .55 | −151 | .55 | +174 | .58 | +154 | .60 | +140 |
| | 10 | .55 | −130 | .55 | −170 | .56 | +164 | .59 | +148 | .61 | +135 |
| | 15 | .55 | −147 | .56 | −178 | .58 | +160 | .62 | +145 | .63 | +133 |
| | 20 | .58 | −165 | .60 | +174 | .62 | +158 | .65 | +144 | .67 | +132 |
| 3 Volts | 1.0 | .85 | −48 | .68 | −100 | .61 | −149 | .62 | +178 | .65 | +156 |
| | 2.5 | .75 | −63 | .58 | −121 | .53 | −169 | .56 | +164 | .59 | +146 |
| | 5.0 | .64 | −82 | .52 | −139 | .51 | +177 | .54 | +156 | .57 | +139 |
| | 10 | .53 | −112 | .48 | −160 | .51 | +167 | .54 | +149 | .56 | +134 |
| | 15 | .49 | −126 | .48 | −168 | .52 | +162 | .55 | +145 | .57 | +132 |
| | 20 | .48 | −137 | .49 | −173 | .53 | +160 | .56 | +145 | .58 | +131 |
| 6 Volts | 1.0 | .87 | −45 | .71 | −94 | .60 | −148 | .60 | +179 | .63 | +156 |
| | 2.5 | .77 | −58 | .60 | −114 | .52 | −164 | .55 | +168 | .57 | +148 |
| | 5.0 | .66 | −75 | .52 | −132 | .48 | −177 | .52 | +159 | .54 | +142 |
| | 10 | .53 | −101 | .46 | −151 | .47 | +171 | .50 | +152 | .53 | +137 |
| | 15 | .47 | −115 | .45 | −162 | .47 | +166 | .51 | +148 | .53 | +135 |
| | 20 | .46 | −125 | .45 | −167 | .48 | +163 | .52 | +147 | .54 | +134 |
| 10 Volts | 1.0 | .88 | −43 | .72 | −91 | .60 | −145 | .60 | −178 | .63 | +158 |
| | 2.5 | .79 | −55 | .60 | −109 | .52 | −160 | .54 | +170 | .57 | +150 |
| | 5.0 | .68 | −70 | .50 | −130 | .47 | −175 | .50 | +160 | .53 | +143 |
| | 10 | .55 | −93 | .45 | −147 | .45 | +173 | .48 | +154 | .52 | +138 |
| | 15 | .50 | −107 | .43 | −158 | .44 | +168 | .49 | +151 | .52 | +136 |
| | 20 | .47 | −116 | .43 | −163 | .45 | +166 | .49 | +150 | .52 | +136 |

TABLE II – $S_{21}$

| FREQUENCY (MHz) | | 200 | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ | $I_C$ | $\|S_{21}\|$ | ∠φ | $\|S_{21}\|$ | ∠φ | $\|S_{21}\|$ | ∠φ | $\|S_{21}\|$ | ∠φ | $\|S_{21}\|$ | ∠φ |
| 1 Volt | 1.0mA | 4.2 | +140 | 2.7 | +104 | 1.4 | +73 | .96 | +52 | .77 | +39 |
| | 2.5 | 7.2 | +130 | 3.9 | +98 | 2.1 | +73 | 1.4 | +55 | 1.1 | +42 |
| | 5.0 | 9.9 | +121 | 4.8 | +92 | 2.6 | +72 | 1.8 | +57 | 1.4 | +44 |
| | 10 | 12.0 | +109 | 5.2 | +87 | 2.8 | +70 | 1.9 | +57 | 1.5 | +44 |
| | 15 | 11.4 | +103 | 4.9 | +84 | 2.7 | +68 | 1.8 | +55 | 1.4 | +42 |
| | 20 | 6.3 | +96 | 2.6 | +81 | 1.9 | +65 | 1.3 | +52 | 1.0 | +41 |
| 3 Volts | 1.0 | 4.5 | +144 | 3.0 | +110 | 1.5 | +78 | 1.0 | +56 | .82 | +43 |
| | 2.5 | 7.8 | +136 | 4.5 | +103 | 2.5 | +76 | 1.7 | +58 | 1.3 | +45 |
| | 5.0 | 11.2 | +127 | 5.7 | +97 | 3.0 | +74 | 2.0 | +58 | 1.6 | +45 |
| | 10 | 14.9 | +116 | 6.8 | +91 | 3.4 | +72 | 2.3 | +58 | 1.8 | +45 |
| | 15 | 16 | +111 | 7.0 | +88 | 3.6 | +70 | 2.4 | +57 | 1.8 | +45 |
| | 20 | 16.4 | +108 | 7.0 | +87 | 3.5 | +69 | 2.4 | +56 | 1.8 | +44 |
| 6 Volts | 1.0 | 4.5 | +146 | 3.1 | +113 | 1.8 | +81 | 1.2 | +60 | .96 | +46 |
| | 2.5 | 7.8 | +139 | 4.8 | +106 | 2.7 | +78 | 1.8 | +60 | 1.4 | +46 |
| | 5.0 | 11.6 | +130 | 6.2 | +99 | 3.3 | +75 | 2.2 | +60 | 1.7 | +47 |
| | 10 | 15.9 | +120 | 7.5 | +92 | 3.8 | +73 | 2.5 | +59 | 1.9 | +47 |
| | 15 | 17.2 | +114 | 7.7 | +90 | 4.0 | +71 | 2.6 | +58 | 2.0 | +46 |
| | 20 | 17.7 | +110 | 7.8 | +88 | 4.0 | +70 | 2.6 | +57 | 2.0 | +45 |
| 10 Volts | 1.0 | 4.5 | +147 | 3.2 | +114 | 1.8 | +82 | 1.2 | +61 | .96 | +47 |
| | 2.5 | 7.8 | +140 | 4.9 | +107 | 2.7 | +79 | 1.8 | +61 | 1.4 | +47 |
| | 5.0 | 11.7 | +132 | 6.4 | +100 | 3.5 | +75 | 2.3 | +60 | 1.8 | +48 |
| | 10 | 15.9 | +121 | 7.6 | +93 | 4.0 | +73 | 2.6 | +58 | 2.0 | +47 |
| | 15 | 17.4 | +115 | 8.0 | +90 | 4.0 | +71 | 2.7 | +57 | 2.0 | +46 |
| | 20 | 17.8 | +112 | 8.0 | +88 | 4.0 | +70 | 2.6 | +56 | 2.0 | +45 |

TABLE III – $S_{12}$

| FREQUENCY (MHz) | | 200 | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ | $I_C$ | $\lvert S_{12} \rvert$ | $\angle\phi$ | $\lvert S_{12} \rvert$ | $\angle\phi$ | $\lvert S_{12} \rvert$ | $\angle\phi$ | $\lvert S_{12} \rvert$ | $\angle\phi$ | $\lvert S_{12} \rvert$ | $\angle\phi$ |
| 1 Volt | 1.0mA | .09 | +57 | .14 | +32 | .15 | +17 | .15 | +13 | .13 | +21 |
| | 2.5 | .08 | +49 | .10 | +32 | .12 | +27 | .13 | +32 | .14 | +40 |
| | 5.0 | .06 | +43 | .08 | +35 | .10 | +42 | .13 | +48 | .16 | +51 |
| | 10 | .05 | +42 | .06 | +45 | .09 | +54 | .13 | +57 | .17 | +57 |
| | 15 | .04 | +43 | .06 | +50 | .09 | +60 | .13 | +60 | .18 | +60 |
| | 20 | .03 | +41 | .05 | +55 | .09 | +63 | .14 | +64 | .18 | +62 |
| 3 Volts | 1.0 | .06 | +61 | .10 | +37 | .13 | +21 | .12 | +20 | .10 | +31 |
| | 2.5 | .06 | +57 | .08 | +36 | .09 | +33 | .10 | +40 | .12 | +49 |
| | 5.0 | .05 | +51 | .07 | +39 | .08 | +45 | .11 | +52 | .14 | +56 |
| | 10 | .04 | +49 | .05 | +49 | .08 | +56 | .11 | +61 | .15 | +61 |
| | 15 | .03 | +49 | .05 | +55 | .08 | +62 | .12 | +64 | .15 | +64 |
| | 20 | .03 | +52 | .04 | +59 | .08 | +65 | .12 | +65 | .15 | +65 |
| 6 Volts | 1.0 | .05 | +63 | .09 | +40 | .10 | +26 | .09 | +29 | .09 | +43 |
| | 2.5 | .05 | +59 | .07 | +39 | .08 | +37 | .09 | +45 | .11 | +55 |
| | 5.0 | .04 | +55 | .05 | +42 | .07 | +48 | .09 | +56 | .12 | +62 |
| | 10 | .03 | +50 | .04 | +51 | .07 | +58 | .10 | +64 | .13 | +66 |
| | 15 | .02 | +53 | .04 | +55 | .07 | +64 | .10 | +67 | .13 | +68 |
| | 20 | .03 | +54 | .04 | +60 | .07 | +66 | .10 | +69 | .13 | +69 |
| 10 Volts | 1.0 | .05 | +65 | .08 | +41 | .09 | +28 | .08 | +32 | .08 | +48 |
| | 2.5 | .04 | +59 | .06 | +42 | .07 | +38 | .08 | +48 | .09 | +59 |
| | 5.0 | .03 | +57 | .05 | +44 | .07 | +51 | .08 | +60 | .11 | +65 |
| | 10 | .03 | +54 | .04 | +51 | .06 | +60 | .09 | +66 | .12 | +69 |
| | 15 | .03 | +52 | .04 | +55 | .06 | +64 | .09 | +68 | .12 | +70 |
| | 20 | .02 | +54 | .03 | +59 | .06 | +66 | .09 | +69 | .12 | +71 |

TABLE IV – $S_{22}$

| FREQUENCY (MHz) | | 200 | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ | $I_C$ | $\lvert S_{22} \rvert$ | $\angle\phi$ | $\lvert S_{22} \rvert$ | $\angle\phi$ | $\lvert S_{22} \rvert$ | $\angle\phi$ | $\lvert S_{22} \rvert$ | $\angle\phi$ | $\lvert S_{22} \rvert$ | $\angle\phi$ |
| 1 Volt | 1.0mA | .88 | −23 | .66 | −41 | .57 | −56 | .54 | −76 | .53 | −96 |
| | 2.5 | .76 | −34 | .48 | −50 | .40 | −61 | .37 | −78 | .37 | −98 |
| | 5.0 | .61 | −45 | .34 | −58 | .25 | −67 | .23 | −84 | .24 | −103 |
| | 10 | .42 | −60 | .20 | −70 | .15 | −75 | .14 | −95 | .16 | −115 |
| | 15 | .31 | −67 | .15 | −77 | .11 | −83 | .11 | −105 | .14 | −125 |
| | 20 | .16 | −72 | .09 | −82 | .10 | −92 | .12 | −119 | .16 | −140 |
| 3 Volts | 1.0 | .91 | −18 | .75 | −32 | .66 | −47 | .62 | −65 | .60 | −82 |
| | 2.5 | .83 | −25 | .60 | −38 | .47 | −50 | .44 | −64 | .43 | −81 |
| | 5.0 | .72 | −32 | .47 | −41 | .36 | −50 | .34 | −64 | .33 | −80 |
| | 10 | .56 | −40 | .34 | −42 | .27 | −49 | .25 | −62 | .25 | −78 |
| | 15 | .48 | −43 | .30 | −41 | .23 | −46 | .21 | −60 | .22 | −76 |
| | 20 | .43 | −43 | .27 | −39 | .22 | −44 | .21 | −58 | .22 | −75 |
| 6 Volts | 1.0 | .93 | −15 | .79 | −27 | .68 | −42 | .65 | −57 | .63 | −74 |
| | 2.5 | .87 | −20 | .67 | −31 | .55 | −42 | .52 | −56 | .51 | −71 |
| | 5.0 | .77 | −26 | .55 | −34 | .45 | −41 | .43 | −53 | .42 | −68 |
| | 10 | .63 | −32 | .43 | −33 | .37 | −38 | .36 | −50 | .35 | −64 |
| | 15 | .57 | −33 | .40 | −31 | .35 | −35 | .34 | −47 | .33 | −62 |
| | 20 | .53 | −33 | .38 | −29 | .34 | −34 | .33 | −46 | .33 | −61 |
| 10 Volts | 1.0 | .94 | −13 | .82 | −25 | .73 | −38 | .69 | −53 | .67 | −69 |
| | 2.5 | .89 | −18 | .70 | −28 | .60 | −38 | .57 | −51 | .56 | −66 |
| | 5.0 | .81 | −23 | .60 | −29 | .50 | −37 | .48 | −48 | .47 | −61 |
| | 10 | .68 | −27 | .50 | −28 | .44 | −34 | .43 | −45 | .42 | −58 |
| | 15 | .62 | −28 | .47 | −26 | .43 | −30 | .42 | −42 | .42 | −56 |
| | 20 | .59 | −27 | .46 | −24 | .43 | −30 | .42 | −42 | .42 | −56 |

**MOTOROLA Semiconductors**

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF902

## Advance Information

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

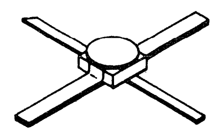
. . . designed for use in high-gain, low-noise, small signal, tuned and wideband amplifiers. Ideal for use in microstrip thin and thick film applications.

- Low Noise Figure —
  NF = 2.0 dB (Typ) @ f = 1.0 GHz
  = 3.3 dB (Typ) @ f = 2.0 GHz
- High Power Gain —
  $G_{max}$ = 16 dB (Typ) @ f = 1.0 GHz
  = 10 dB (Typ) @ f = 2.0 GHz

NF = 2.0 dB @ 1.0 GHz

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**

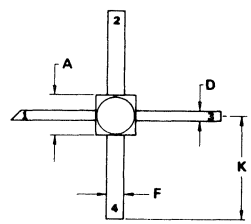


### MAXIMUM RATINGS

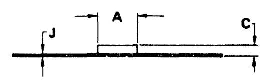
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 25 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current — Peak | $I_C$ | 30 | mAdc |
| Total Device Dissipation @ $T_C$ = 100°C<br>Derate Above 100°C | $P_D$ | 400<br>4.0 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 250 | °C/W |



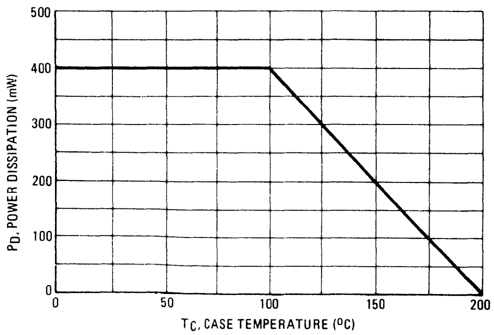

STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER




| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 2.29 | 2.67 | 0.090 | 0.105 |
| C | 0.89 | 1.40 | 0.035 | 0.055 |
| D | 0.41 | 0.61 | 0.016 | 0.024 |
| F | 0.89 | 1.09 | 0.035 | 0.043 |
| J | 0.08 | 0.15 | 0.003 | 0.006 |
| K | 4.45 | 5.84 | 0.175 | 0.230 |

CASE 303-01

FIGURE 1 — POWER DERATING




This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 25 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C$ = 15 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | $f_T$ | – | 4.5 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.4 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 2.0 | 2.5 | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 3.3 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 13 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 8.0 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 15 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | 14 | 16 | – | |
| ($I_C$ = 15 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 10 | – | |

(1) $G_{max} = \dfrac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

**FIGURE 2 – POWER GAIN AND NOISE FIGURE versus FREQUENCY**

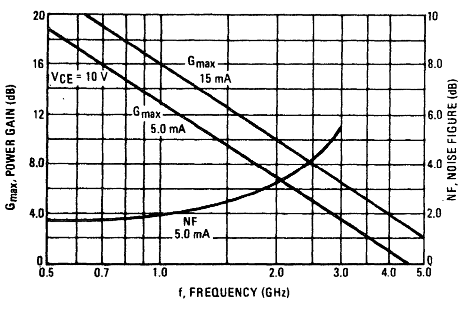



**FIGURE 3 – POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT**

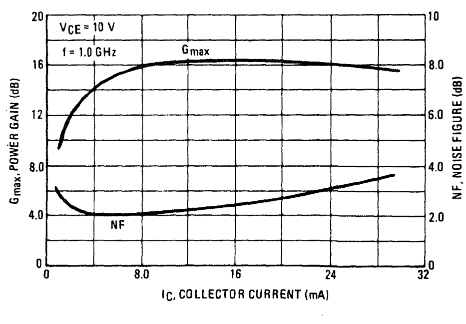


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ |
| 5.0 | 2.0 | 0.74 | -110 | 0.70 | -150 | 0.70 | -170 | 0.71 | 175 |
| | 5.0 | 0.69 | -130 | 0.68 | -165 | 0.68 | 175 | 0.70 | 165 |
| | 15 | 0.68 | -160 | 0.69 | 175 | 0.70 | 165 | 0.72 | 155 |
| | 25 | 0.69 | -170 | 0.70 | 175 | 0.71 | 165 | 0.73 | 155 |
| 10 | 2.5 | 0.74 | -105 | 0.69 | -150 | 0.70 | -170 | 0.71 | 175 |
| | 5.0 | 0.69 | -0.30 | 0.67 | -165 | 0.68 | 180 | 0.69 | 165 |
| | 15 | 0.66 | -160 | 0.67 | 180 | 0.68 | 165 | 0.70 | 160 |
| | 25 | 0.67 | -165 | 0.68 | 175 | 0.69 | 165 | 0.71 | 155 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| 5.0 | 2.5 | 0.68 | -35 | 0.57 | -50 | 0.54 | -65 | 0.54 | -75 |
| | 5.0 | 0.54 | -40 | 0.44 | -50 | 0.43 | -65 | 0.43 | -75 |
| | 15 | 0.35 | -45 | 0.31 | -50 | 0.32 | -60 | 0.33 | -75 |
| | 25 | 0.34 | -35 | 0.32 | -45 | 0.33 | -55 | 0.35 | -70 |
| 10 | 2.5 | 0.71 | -25 | 0.61 | -45 | 0.58 | -60 | 0.58 | -70 |
| | 5.0 | 0.58 | -35 | 0.49 | -45 | 0.47 | -60 | 0.48 | -70 |
| | 15 | 0.42 | -35 | 0.38 | -40 | 0.38 | -55 | 0.40 | -65 |
| | 25 | 0.40 | -30 | 0.39 | -40 | 0.40 | -50 | 0.42 | -65 |

FIGURE 6 - $S_{21}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| 5.0 | 2.5 | 4.62 | 110 | 2.65 | 85 | 1.81 | 65 | 1.41 | 50 |
| | 5.0 | 6.44 | 100 | 3.45 | 80 | 2.31 | 65 | 1.81 | 50 |
| | 15 | 8.17 | 90 | 4.17 | 75 | 2.75 | 60 | 2.15 | 50 |
| | 25 | 8.19 | 85 | 4.15 | 70 | 2.72 | 55 | 2.10 | 45 |
| 10 | 2.5 | 4.78 | 110 | 2.77 | 85 | 1.90 | 65 | 1.48 | 50 |
| | 5.0 | 6.72 | 105 | 3.61 | 80 | 2.42 | 65 | 1.89 | 50 |
| | 15 | 8.52 | 90 | 4.37 | 75 | 2.88 | 60 | 2.23 | 50 |
| | 25 | 8.41 | 85 | 4.27 | 70 | 2.79 | 55 | 2.16 | 45 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 0.1 | 2.5 | 0.08 | 35 | 0.10 | 20 | 0.09 | 15 | 0.09 | 15 |
| | 5.0 | 0.06 | 30 | 0.07 | 25 | 0.07 | 30 | 0.08 | 35 |
| | 15 | 0.04 | 40 | 0.05 | 45 | 0.06 | 50 | 0.08 | 55 |
| | 25 | 0.03 | 45 | 0.04 | 55 | 0.06 | 60 | 0.07 | 60 |
| 10 | 2.5 | 0.08 | 35 | 0.09 | 20 | 0.08 | 20 | 0.08 | 20 |
| | 5.0 | 0.06 | 30 | 0.06 | 25 | 0.07 | 30 | 0.07 | 35 |
| | 15 | 0.03 | 40 | 0.04 | 45 | 0.06 | 50 | 0.07 | 55 |
| | 25 | 0.03 | 45 | 0.04 | 55 | 0.06 | 60 | 0.07 | 60 |

**MOTOROLA**
**Semiconductors**
BOX 20912 • PHOENIX, ARIZONA 85036

# MRF904

## The RF Line

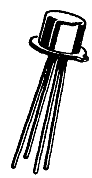
### NPN SILICON HIGH-FREQUENCY TRANSISTORS

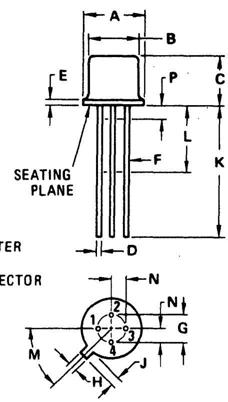
. . . designed for use as low-noise, high-gain, general purpose amplifiers.

- High Current-Gain — Bandwidth Product —
  $f_T$ = 4.0 GHz (Typ) @ $I_C$ = 15 mAdc
- Low Noise Figure —
  NF = 1.5 dB (Typ) @ f = 450 MHz
  = 2.5 dB (Typ) @ f = 1.0 GHz
- High Power Gain —
  $G_{max}$ = 16 dB (Typ) @ f = 450 MHz
  = 10 dB (Typ) @ f = 1.0 GHz
- Excellent Third Order Intercept — +25 dBm (Typ)

**HIGH FREQUENCY TRANSISTORS**

**NPN SILICON**






STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | $45^o$ BSC | | $45^o$ BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

**CASE 20-03**
**TO-72**

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 15 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 25 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 30 | mAdc |
| Total Power Dissipation @ $T_A = 25^oC$<br>Derate above $25^oC$ | $P_D$ | 0.2<br>1.14 | Watt<br>$mW/^oC$ |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | $^oC$ |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 15 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 25 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 5.0 mAdc, $V_{CE}$ = 5.0 Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 15 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | $f_T$ | – | 4.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | – | 1.0 | pF |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 450 MHz) | | – | 1.5 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 1.0 GHz) | | – | 2.5 | – | |
| **FUNCTIONAL TEST** | | | | | |
| Unilateralized Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 450 MHz) | | – | 16 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 6.0 Vdc, f = 1.0 GHz) | | – | 10 | – | |

(1) $G_{max} = \dfrac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

FIGURE 1 — NOISE FIGURE versus FREQUENCY

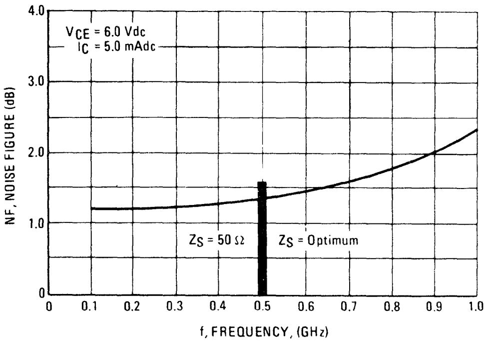



FIGURE 2 — NOISE FIGURE versus COLLECTOR CURRENT

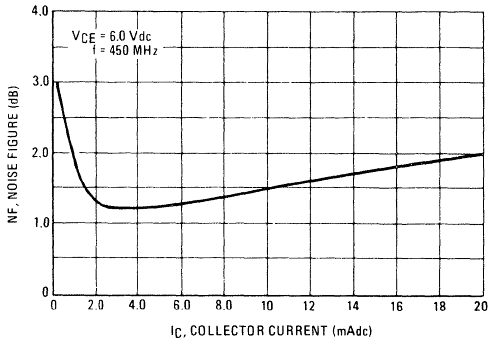



FIGURE 3 — COLLECTOR-BASE CAPACITANCE versus COLLECTOR-BASE VOLTAGE

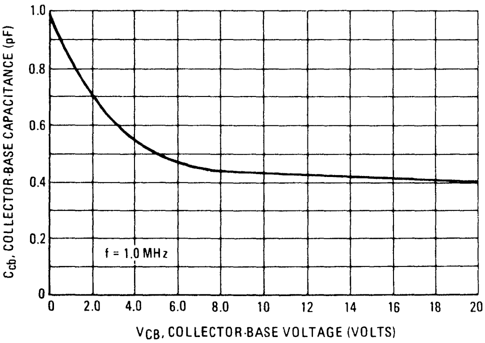



FIGURE 4 — UNILATERALIZED GAIN ($G_{max}$) versus FREQUENCY

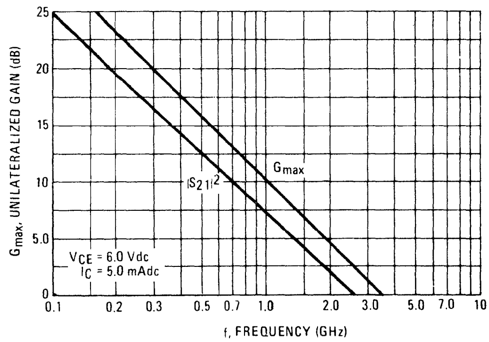



FIGURE 5 — CURRENT-GAIN — BANDWIDTH PRODUCT versus COLLECTOR CURRENT

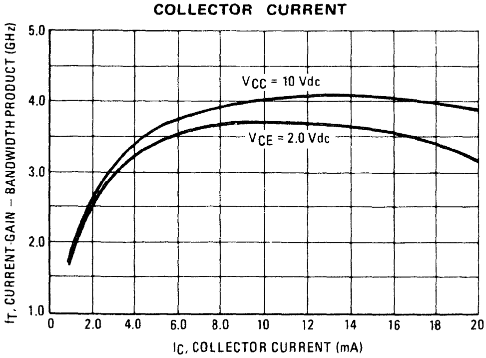



FIGURE 6 — INTERMODULATION DISTORTION versus COLLECTOR CURRENT

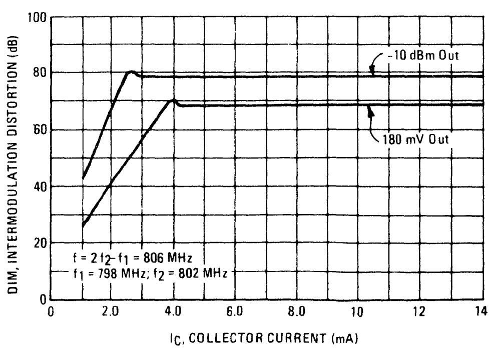


TABLE 1 – $S_{11}$ PARAMETERS

| $V_{CC}$ (Volts) | $I_C$ (mA) | 100 S11 | 100 ∠φ | 200 S11 | 200 ∠φ | 500 S11 | 500 ∠φ | 800 S11 | 800 ∠φ | 1000 S11 | 1000 ∠φ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 1.0 | 0.941 | -22 | 0.85 | -43 | 0.57 | -91 | 0.37 | -128 | 0.30 | -151 |
| | 2.5 | 0.85 | -31 | 0.67 | -57 | 0.35 | -102 | 0.20 | -136 | 0.14 | -157 |
| | 5.0 | 0.69 | -44 | 0.46 | -71 | 0.21 | -109 | 0.10 | -144 | 0.069 | -166 |
| | 10 | 0.45 | -67 | 0.28 | -94 | 0.13 | -136 | 0.087 | 172 | 0.075 | 145 |
| | 15 | 0.37 | -110 | 0.31 | -145 | 0.26 | 170 | 0.27 | 139 | 0.27 | 122 |
| | 30 | 0.71 | -178 | 0.71 | 169 | 0.68 | 144 | 0.68 | 121 | 0.65 | 107 |
| 3.0 | 1.0 | 0.94 | -19 | 0.87 | -37 | 0.61 | -80 | 0.39 | -114 | 0.30 | -134 |
| | 2.5 | 0.87 | -26 | 0.71 | -47 | 0.39 | -84 | 0.21 | -106 | 0.15 | -115 |
| | 5.0 | 0.74 | -34 | 0.52 | -55 | 0.25 | -77 | 0.13 | -82 | 0.109 | -79 |
| | 10 | 0.55 | -42 | 0.35 | -58 | 0.18 | -66 | 0.11 | -60 | 0.105 | -55 |
| | 15 | 0.46 | -46 | 0.28 | -59 | 0.15 | -64 | 0.096 | -55 | 0.092 | -49 |
| | 30 | 0.28 | -95 | 0.21 | -134 | 0.16 | 175 | 0.17 | 135 | 0.17 | 116 |
| 6.0 | 1.0 | 0.95 | -18 | 0.88 | -35 | 0.63 | -76 | 0.40 | -108 | 0.30 | -126 |
| | 2.5 | 0.89 | -23 | 0.74 | -43 | 0.42 | -77 | 0.23 | -94 | 0.17 | -100 |
| | 5.0 | 0.77 | -31 | 0.56 | -49 | 0.29 | -67 | 0.18 | -69 | 0.15 | -66 |
| | 10 | 0.61 | -37 | 0.40 | -50 | 0.23 | -55 | 0.16 | -51 | 0.16 | -50 |
| | 15 | 0.52 | -40 | 0.34 | -51 | 0.20 | -52 | 0.15 | -47 | 0.15 | -47 |
| | 30 | 0.36 | -55 | 0.21 | -70 | 0.098 | -77 | 0.037 | -59 | 0.033 | -27 |
| 10 | 1.0 | 0.96 | -17 | 0.89 | -33 | 0.65 | -73 | 0.41 | -103 | 0.31 | -121 |
| | 2.5 | 0.89 | -22 | 0.76 | -41 | 0.44 | -73 | 0.25 | -88 | 0.18 | -93 |
| | 5.0 | 0.79 | -28 | 0.59 | -46 | 0.32 | -63 | 0.20 | -65 | 0.18 | -63 |
| | 10 | 0.64 | -34 | 0.44 | -47 | 0.26 | -52 | 0.19 | -49 | 0.18 | -49 |
| | 15 | 0.57 | -37 | 0.38 | -48 | 0.23 | -49 | 0.18 | -46 | 0.17 | -46 |
| | 30 | 0.41 | -51 | 0.24 | -64 | 0.12 | -67 | 0.061 | -52 | 0.055 | -36 |

TABLE 2 – $S_{21}$ PARAMETERS

| $V_{CC}$ (Volts) | $I_C$ (mA) | 100 S21 | 100 ∠φ | 200 S21 | 200 ∠φ | 500 S21 | 500 ∠φ | 800 S21 | 800 ∠φ | 1000 S21 | 1000 ∠φ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 1.0 | 5.32 | 156 | 3.06 | 137 | 2.22 | 97 | 1.65 | 70 | 1.44 | 56 |
| | 2.5 | 6.79 | 146 | 5.57 | 124 | 3.15 | 86 | 2.14 | 64 | 1.81 | 52 |
| | 5.0 | 10.97 | 133 | 7.60 | 110 | 3.62 | 79 | 2.38 | 61 | 2.00 | 49 |
| | 10 | 13.16 | 118 | 8.07 | 99 | 3.60 | 74 | 2.35 | 57 | 1.96 | 46 |
| | 15 | 9.84 | 108 | 5.66 | 91 | 2.44 | 67 | 1.63 | 49 | 1.38 | 38 |
| | 30 | 1.65 | 83 | 0.88 | 69 | 0.47 | 46 | 0.43 | 37 | 0.45 | 31 |
| 3.0 | 1.0 | 3.33 | 159 | 3.11 | 142 | 2.36 | 103 | 1.79 | 76 | 1.55 | 62 |
| | 2.5 | 6.89 | 150 | 5.85 | 129 | 3.48 | 92 | 2.38 | 70 | 2.00 | 58 |
| | 5.0 | 11.49 | 138 | 8.34 | 115 | 4.12 | 84 | 2.70 | 66 | 2.25 | 55 |
| | 10 | 15.71 | 125 | 9.82 | 104 | 4.39 | 79 | 2.85 | 63 | 2.34 | 53 |
| | 15 | 16.97 | 119 | 10.05 | 100 | 4.39 | 77 | 2.83 | 61 | 2.34 | 52 |
| | 30 | 12.66 | 108 | 7.02 | 92 | 2.98 | 70 | 1.94 | 54 | 1.61 | 44 |
| 6.0 | 1.0 | 3.31 | 160 | 3.10 | 144 | 2.41 | 106 | 1.83 | 79 | 1.60 | 65 |
| | 2.5 | 6.80 | 151 | 5.85 | 131 | 3.60 | 94 | 2.46 | 77 | 2.07 | 60 |
| | 5.0 | 11.44 | 140 | 8.54 | 117 | 4.28 | 86 | 2.83 | 68 | 2.33 | 57 |
| | 10 | 15.85 | 127 | 10.14 | 107 | 4.61 | 81 | 2.96 | 65 | 2.46 | 55 |
| | 15 | 17.20 | 122 | 10.47 | 102 | 4.60 | 79 | 2.96 | 63 | 2.45 | 54 |
| | 30 | 16.37 | 113 | 9.38 | 96 | 4.00 | 75 | 2.58 | 59 | 2.14 | 49 |
| 10 | 1.0 | 3.25 | 160 | 3.08 | 145 | 2.40 | 108 | 1.83 | 81 | 1.61 | 67 |
| | 2.5 | 6.73 | 152 | 5.85 | 132 | 3.63 | 96 | 2.50 | 74 | 2.10 | 62 |
| | 5.0 | 11.19 | 142 | 8.49 | 119 | 4.34 | 88 | 2.85 | 69 | 2.37 | 59 |
| | 10 | 15.59 | 129 | 10.16 | 108 | 4.66 | 82 | 3.00 | 66 | 2.47 | 56 |
| | 15 | 17.04 | 124 | 10.49 | 104 | 4.65 | 80 | 2.99 | 64 | 2.47 | 55 |
| | 30 | 16.18 | 115 | 9.38 | 98 | 4.03 | 96 | 2.60 | 60 | 2.14 | 50 |

TABLE 3 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 100 | | 200 | | 500 | | 800 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 1.0 | 1.0 | 0.054 | 73 | 0.097 | 61 | 0.159 | 41 | 0.184 | 36 | 0.194 | 37 |
| | 2.5 | 0.051 | 69 | 0.084 | 58 | 0.140 | 50 | 0.189 | 48 | 0.220 | 46 |
| | 5.0 | 0.046 | 65 | 0.072 | 60 | 0.137 | 58 | 0.201 | 53 | 0.239 | 50 |
| | 10 | 0.041 | 64 | 0.067 | 64 | 0.142 | 62 | 0.215 | 56 | 0.256 | 51 |
| | 15 | 0.043 | 61 | 0.070 | 63 | 0.152 | 62 | 0.230 | 55 | 0.277 | 50 |
| | 30 | 0.058 | 50 | 0.093 | 58 | 0.209 | 57 | 0.311 | 46 | 0.372 | 39 |
| 3.0 | 1.0 | 0.039 | 75 | 0.072 | 65 | 0.123 | 46 | 0.143 | 42 | 0.151 | 44 |
| | 2.5 | 0.037 | 72 | 0.063 | 62 | 0.110 | 54 | 0.150 | 53 | 0.174 | 52 |
| | 5.0 | 0.033 | 70 | 0.055 | 64 | 0.108 | 62 | 0.160 | 58 | 0.190 | 55 |
| | 10 | 0.030 | 70 | 0.050 | 68 | 0.109 | 67 | 0.165 | 61 | 0.199 | 57 |
| | 15 | 0.028 | 70 | 0.049 | 70 | 0.109 | 68 | 0.167 | 62 | 0.200 | 57 |
| | 30 | 0.026 | 68 | 0.046 | 70 | 0.105 | 69 | 0.165 | 64 | 0.200 | 61 |
| 6.0 | 1.0 | 0.032 | 76 | 0.060 | 66 | 0.106 | 49 | 0.123 | 45 | 0.131 | 48 |
| | 2.5 | 0.031 | 73 | 0.054 | 64 | 0.095 | 57 | 0.130 | 56 | 0.151 | 55 |
| | 5.0 | 0.028 | 71 | 0.048 | 66 | 0.094 | 64 | 0.139 | 61 | 0.165 | 58 |
| | 10 | 0.026 | 71 | 0.043 | 69 | 0.094 | 68 | 0.144 | 63 | 0.172 | 59 |
| | 15 | 0.024 | 71 | 0.042 | 71 | 0.093 | 69 | 0.144 | 64 | 0.172 | 60 |
| | 30 | 0.021 | 71 | 0.037 | 72 | 0.086 | 71 | 0.134 | 67 | 0.162 | 63 |
| 10 | 1.0 | 0.028 | 77 | 0.053 | 68 | 0.095 | 50 | 0.109 | 47 | 0.116 | 50 |
| | 2.5 | 0.027 | 74 | 0.048 | 65 | 0.085 | 58 | 0.116 | 57 | 0.134 | 57 |
| | 5.0 | 0.025 | 73 | 0.043 | 67 | 0.084 | 64 | 0.125 | 62 | 0.148 | 60 |
| | 10 | 0.023 | 72 | 0.037 | 69 | 0.084 | 69 | 0.128 | 64 | 0.153 | 61 |
| | 15 | 0.022 | 73 | 0.037 | 70 | 0.084 | 69 | 0.128 | 65 | 0.152 | 62 |
| | 30 | 0.019 | 72 | 0.033 | 72 | 0.076 | 72 | 0.119 | 68 | 0.143 | 66 |

TABLE 4 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 100 | | 200 | | 500 | | 800 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CC}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| 1.0 | 1.0 | 0.966 | -12 | 0.893 | -23 | 0.693 | -41 | 0.612 | -53 | 0.594 | -59 |
| | 2.5 | 0.901 | -18 | 0.760 | -29 | 0.548 | -42 | 0.498 | -51 | 0.494 | -56 |
| | 5.0 | 0.793 | -24 | 0.619 | -32 | 0.456 | -39 | 0.429 | -49 | 0.439 | -54 |
| | 10 | 0.635 | -29 | 0.486 | -32 | 0.390 | -36 | 0.377 | -47 | 0.389 | -53 |
| | 15 | 0.453 | -29 | 0.364 | -29 | 0.313 | -34 | 0.309 | -48 | 0.321 | -14 |
| | 30 | 0.048 | -78 | 0.035 | -88 | 0.032 | -135 | 0.031 | -162 | 0.007 | -167 |
| 3.0 | 1.0 | 0.976 | -9.0 | 0.926 | -18 | 0.770 | -35 | 0.702 | -46 | 0.683 | -51 |
| | 2.5 | 0.935 | -13 | 0.828 | -23 | 0.648 | -35 | 0.608 | -43 | 0.608 | -48 |
| | 5.0 | 0.853 | -18 | 0.712 | -25 | 0.577 | -32 | 0.555 | -41 | 0.565 | -46 |
| | 10 | 0.758 | -20 | 0.629 | -23 | 0.539 | -29 | 0.529 | -39 | 0.544 | -44 |
| | 15 | 0.711 | -20 | 0.601 | -22 | 0.533 | -27 | 0.526 | -38 | 0.540 | -44 |
| | 30 | 0.631 | -15 | 0.576 | -16 | 0.548 | -25 | 0.546 | -38 | 0.558 | -45 |
| 6.0 | 1.0 | 0.982 | -8.0 | 0.939 | -16 | 0.803 | -31 | 0.742 | 42 | 0.734 | -47 |
| | 2.5 | 0.947 | -11 | 0.861 | -20 | 0.699 | -31 | 0.662 | -40 | 0.660 | -45 |
| | 5.0 | 0.882 | -15 | 0.759 | -21 | 0.633 | -29 | 0.617 | -31 | 0.627 | -43 |
| | 10 | 0.801 | -17 | 0.684 | -20 | 0.607 | -26 | 0.601 | -35 | 0.610 | -41 |
| | 15 | 0.769 | -17 | 0.667 | -19 | 0.602 | -25 | 0.601 | -35 | 0.607 | -40 |
| | 30 | 0.737 | -14 | 0.672 | -15 | 0.640 | -22 | 0.641 | -33 | 0.655 | -40 |
| 10 | 1.0 | 0.983 | -7.0 | 0.949 | -14 | 0.830 | -29 | 0.774 | -39 | 0.765 | -40 |
| | 2.5 | 0.954 | -10 | 0.880 | -18 | 0.733 | -29 | 0.698 | -37 | 0.702 | -42 |
| | 5.0 | 0.901 | -13 | 0.793 | -19 | 0.676 | -27 | 0.659 | -35 | 0.668 | -41 |
| | 10 | 0.834 | -15 | 0.725 | -18 | 0.646 | -24 | 0.646 | -33 | 0.658 | -39 |
| | 15 | 0.802 | -15 | 0.706 | -17 | 0.645 | -23 | 0.648 | -33 | 0.661 | -39 |
| | 30 | 0.776 | -13 | 0.712 | -14 | 0.678 | -22 | 0.686 | -32 | 0.699 | -38 |

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# MRF905

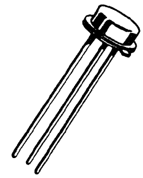
## The RF Line

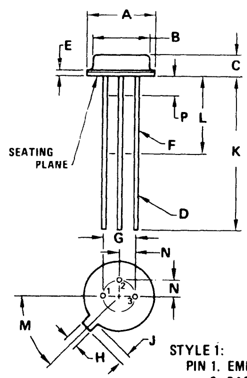
**400 mW**
**RF OSCILLATOR TRANSISTOR**
**NPN SILICON**

### NPN SILICON OSCILLATOR TRANSISTOR

. . . designed for microwave communications relay links and low-cost radiosonde service.

- Emitter Ballasted
- Low Current Density for Improved Lifetime
- Collector Connected to Case






STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 1.65 | 2.16 | 0.065 | 0.085 |
| D | 0.406 | 0.533 | 0.016 | 0.021 |
| E | – | 1.02 | – | 0.040 |
| F | 0.305 | 0.483 | 0.012 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.914 | 1.17 | 0.036 | 0.046 |
| J | 0.711 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

All JEDEC dimensions and notes apply

CASE 26-03
TO-46

### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 20 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 35 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.5 | Vdc |
| Collector Current – Continuous | $I_C$ | 150 | mAdc |
| Total Power Dissipation @ $T_C = 100°C$<br>Derate above 25°C | $P_D$ | 2.5<br>40 | Watts<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

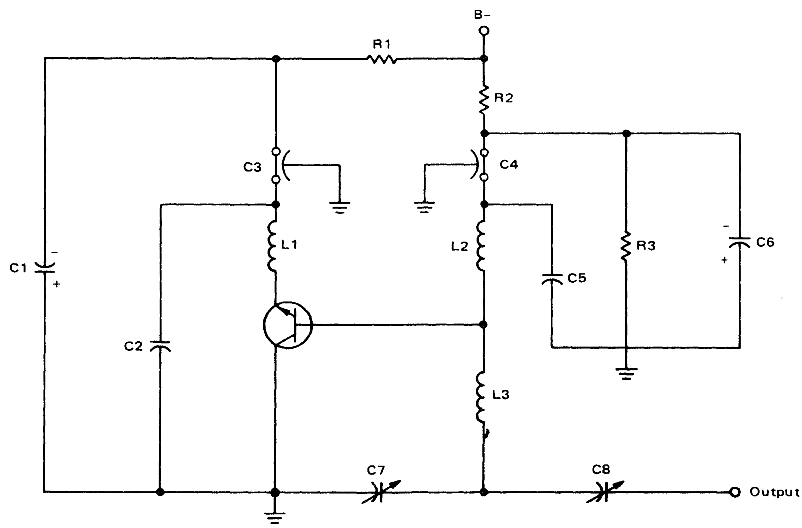
### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 25 | °C/W |

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 10 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 20 | 30 | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 35 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.5 | 5.0 | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 20 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 0.1 | mAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 20 | 60 | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain – Bandwidth Product ($I_C$ = 100 mAdc, $V_{CE}$ = 10 Vdc, f = 200 MHz) | $f_T$ | – | 2500 | – | MHz |
| Output Capacitance ($V_{CB}$ = 20 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{ob}$ | – | 3.0 | 5.0 | pF |
| **FUNCTIONAL TEST** | | | | | |
| Common-Collector Oscillator Output Power ($V_E$ = -20 Vdc, $I_E \cong$ 110 mAdc, f $\cong$ 1.68 GHz) | $P_{out}$ | 400 | 500 | – | mW |

FIGURE 1 – 1.68 GHz OSCILLATOR TEST CIRCUIT SCHEMATIC




| | | | |
|---|---|---|---|
| C1,C6 | 1.0 µF, 35 Vdc TANTALUM | R1 | 47 Ohms, 1/4 Watt |
| C2,C5 | 0.1 µF Ceramic Disk | R2 | 510 Ohms, 1/4 Watt |
| C3,C4 | 680 pF Feedthru | R3 | 1.5 kΩ, 1/4 Watt |
| C7,C8 | 0.4-6.0 pF JOHANSON | L1,L2 | 5 Turns, #22 AWG, 0.125" I.D. |
| | | L3 | #20 AWG, 0.4" Length. |

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# MRF911

## Advance Information

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

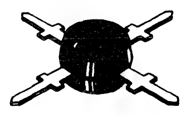
. . . designed primarily for use in high-gain, low-noise tuned and wideband small-signal amplifiers. Excellent in high-speed switching applications.

- High Current-Gain – Bandwidth Product – $f_T$ = 5.0 GHz (Typ) @ f = 1.0 GHz
- High Power Gain – $G_{max}$ = 12.5 dB (Typ) @ f = 1.0 GHz

$f_T$ = 5.0 GHz @ 30 mA

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**

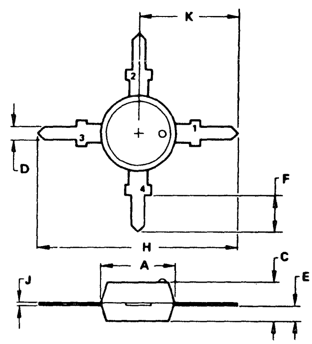


**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 12 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current — Peak | $I_C$ | 40 | mAdc |
| Total Device Dissipation @ $T_L$ = 50°C<br>Derate Above 50°C | $P_D$ | 400<br>4.0 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

**THERMAL CHARACTERISTICS**

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Lead | $R_{\theta JL}$ | 250 | °C/W |

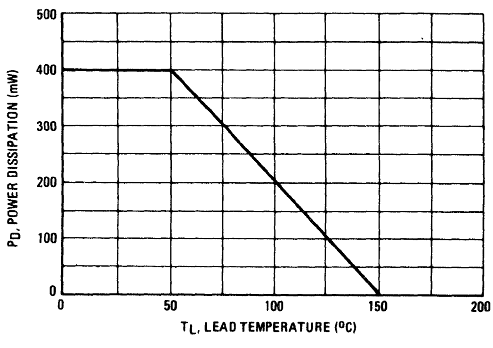



STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | – | 4.78 | – | 0.188 |
| C | – | 3.05 | – | 0.120 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 0.97 | 1.22 | 0.038 | 0.048 |
| F | 2.21 | 2.46 | 0.087 | 0.097 |
| H | 12.40 | 12.90 | 0.488 | 0.508 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 6.20 | 6.45 | 0.244 | 0.254 |

CASE 302-01

**FIGURE 1 – POWER DERATING**




This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 12 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 20 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | $f_T$ | – | 5.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.6 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 2.5 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 4.0 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 10 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 6.0 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 12.5 | – | |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 7.5 | – | |

(1) $G_{max} = \frac{|S_{21}|^2}{((1-|S_{11}|^2)(1-|S_{22}|^2)}$

**FIGURE 2 – POWER GAIN AND NOISE FIGURE versus FREQUENCY**

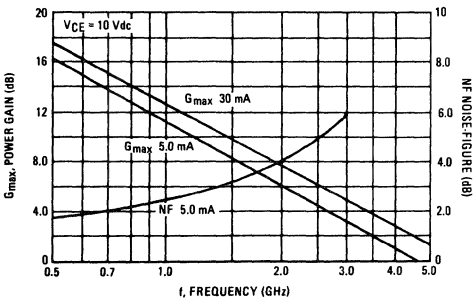



**FIGURE 3 – POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT**

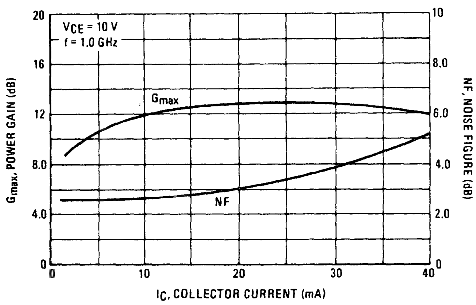


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ |
| 5.0 | 2.0 | 0.66 | -125 | 0.64 | -175 | 0.68 | 160 | 0.73 | 140 |
| | 5.0 | 0.57 | -150 | 0.58 | 170 | 0.62 | 150 | 0.66 | 135 |
| | 10 | 0.54 | -165 | 0.57 | 160 | 0.60 | 145 | 0.64 | 130 |
| | 20 | 0.54 | -180 | 0.57 | 155 | 0.60 | 140 | 0.64 | 125 |
| | 30 | 0.54 | 175 | 0.57 | 155 | 0.61 | 140 | 0.65 | 125 |
| 10 | 2.0 | 0.66 | -120 | 0.63 | -170 | 0.67 | 160 | 0.71 | 140 |
| | 5.0 | 0.56 | -145 | 0.56 | 175 | 0.60 | 150 | 0.64 | 135 |
| | 10 | 0.51 | -160 | 0.53 | 165 | 0.57 | 145 | 0.61 | 130 |
| | 20 | 0.49 | -175 | 0.52 | 160 | 0.57 | 145 | 0.60 | 130 |
| | 30 | 0.49 | -175 | 0.53 | 160 | 0.57 | 145 | 0.61 | 130 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| 5.0 | 2.0 | 0.61 | -45 | 0.50 | -60 | 0.48 | -80 | 0.50 | -100 |
| | 5.0 | 0.40 | -55 | 0.31 | -65 | 0.30 | -85 | 0.32 | -100 |
| | 10 | 0.27 | -60 | 0.20 | -70 | 0.20 | -90 | 0.23 | -105 |
| | 20 | 0.19 | -70 | 0.13 | -75 | 0.14 | -95 | 0.17 | -110 |
| | 30 | 0.16 | -70 | 0.11 | -75 | 0.13 | -95 | 0.16 | -110 |
| 10 | 2.0 | 0.66 | -35 | 0.55 | -50 | 0.53 | -70 | 0.54 | -90 |
| | 5.0 | 0.47 | -45 | 0.38 | -50 | 0.37 | -70 | 0.38 | -75 |
| | 10 | 0.35 | -45 | 0.28 | -50 | 0.27 | -65 | 0.29 | -85 |
| | 20 | 0.26 | -45 | 0.22 | -50 | 0.22 | -65 | 0.24 | -80 |
| | 30 | 0.25 | -40 | 0.21 | -45 | 0.22 | -60 | 0.24 | -80 |

FIGURE 6 – $S_{21}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| 5.0 | 2.0 | 3.24 | 100 | 1.84 | 70 | 1.23 | 50 | 0.96 | 35 |
| | 5.0 | 4.85 | 90 | 2.60 | 70 | 1.76 | 50 | 1.38 | 40 |
| | 10 | 5.78 | 85 | 3.04 | 70 | 2.05 | 50 | 1.61 | 40 |
| | 20 | 6.40 | 85 | 3.30 | 65 | 2.23 | 50 | 1.24 | 40 |
| | 30 | 6.47 | 80 | 3.35 | 65 | 2.26 | 50 | 1.76 | 40 |
| 10 | 2.0 | 3.42 | 100 | 1.95 | 70 | 1.31 | 50 | 1.01 | 35 |
| | 5.0 | 5.20 | 95 | 2.80 | 70 | 1.89 | 50 | 1.45 | 40 |
| | 10 | 6.22 | 90 | 3.28 | 70 | 2.20 | 55 | 1.71 | 40 |
| | 20 | 6.82 | 85 | 3.55 | 65 | 2.37 | 55 | 1.84 | 40 |
| | 30 | 6.90 | 85 | 3.55 | 65 | 2.36 | 50 | 1.81 | 40 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 5.0 | 2.0 | 0.11 | 30 | 0.12 | 25 | 0.11 | 35 | 0.13 | 50 |
| | 5.0 | 0.08 | 40 | 0.10 | 45 | 0.13 | 55 | 0.17 | 55 |
| | 10 | 0.07 | 50 | 0.10 | 55 | 0.14 | 60 | 0.19 | 60 |
| | 20 | 0.06 | 60 | 0.11 | 65 | 0.15 | 65 | 0.20 | 60 |
| | 30 | 0.06 | 65 | 0.11 | 65 | 0.15 | 65 | 0.20 | 60 |
| 10 | 2.0 | 0.10 | 35 | 0.10 | 30 | 0.10 | 40 | 0.12 | 55 |
| | 5.0 | 0.07 | 40 | 0.09 | 45 | 0.12 | 55 | 0.15 | 60 |
| | 10 | 0.06 | 50 | 0.09 | 55 | 0.13 | 60 | 0.17 | 60 |
| | 20 | 0.06 | 60 | 0.10 | 65 | 0.13 | 65 | 0.18 | 60 |
| | 30 | 0.06 | 60 | 0.10 | 65 | 0.14 | 65 | 0.18 | 65 |

MOTOROLA Semiconductors

BOX 20912 • PHOENIX, ARIZONA 85036

# MRF912

## Advance Information

## The RF Line

NF= 2.5 dB @ 1.0 GHz

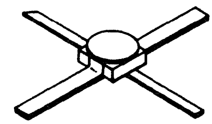
HIGH FREQUENCY TRANSISTOR

NPN SILICON

### NPN SILICON HIGH FREQUENCY TRANSISTOR

. . . designed for use in high-gain, low-noise small-signal tuned and wideband amplifiers. Ideal for use in microstrip thin and thick film applications.

- Low Noise Figure —
  NF = 2.5 db (Typ) @ f = 1.0 GHz
  4.0 dB (Typ) @ f = 2.0 GHz
- High Power Gain —
  $G_{max}$ = 16.5 dB (Typ) @ f = 1.0 GHz
  11 dB (Typ) @ f = 2.0 GHz

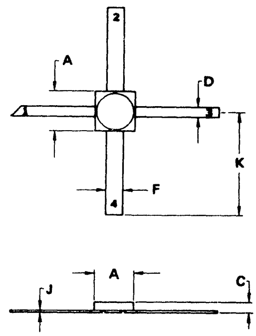


### MAXIMUM RATINGS

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 12 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current — Peak | $I_C$ | 50 | mAdc |
| Total Device Dissipation @ $T_C$ = 75°C<br>Derate Above 75°C | $P_D$ | 500<br>4.0 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Case | $R_{\theta JC}$ | 250 | °C/W |

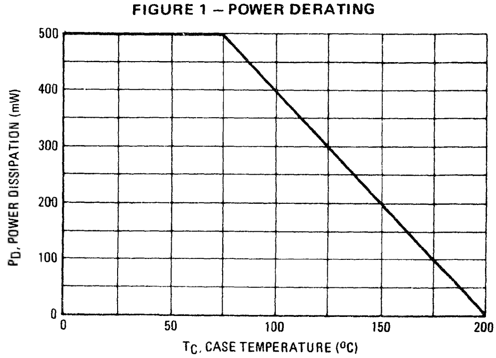



STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 2.29 | 2.67 | 0.090 | 0.105 |
| C | 0.89 | 1.40 | 0.035 | 0.055 |
| D | 0.41 | 0.61 | 0.016 | 0.024 |
| F | 0.89 | 1.09 | 0.035 | 0.043 |
| J | 0.08 | 0.15 | 0.003 | 0.006 |
| K | 4.45 | 5.84 | 0.175 | 0.230 |

CASE 303-01

FIGURE 1 — POWER DERATING




This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 1.0 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 12 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 20 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 15 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | $f_T$ | – | 5.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.6 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 2.5 | 3.0 | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 4.0 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | – | 12 | – | |
| ($I_C$ = 5.0 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 7.0 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 1.0 GHz) | | 14 | 16.5 | – | |
| ($I_C$ = 30 mAdc, $V_{CE}$ = 10 Vdc, f = 2.0 GHz) | | – | 11 | – | |

(1) $G_{max} = \frac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

**FIGURE 2 – POWER GAIN AND NOISE FIGURE versus FREQUENCY**

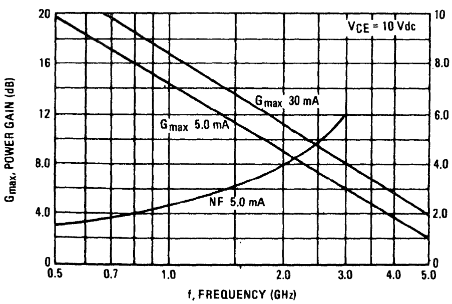



**FIGURE 3 – POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT**

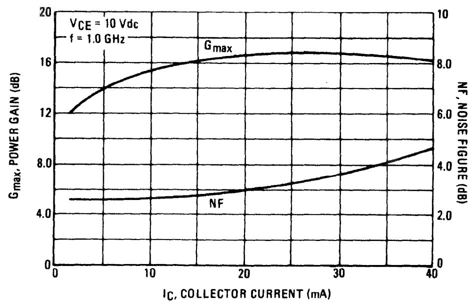


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | $\angle\phi$ | S11 | $\angle\phi$ | S11 | $\angle\phi$ | S11 | $\angle\phi$ |
| 5.0 | 2.0 | 0.76 | -120 | 0.74 | -160 | 0.76 | -175 | 0.79 | 175 |
| | 5.0 | 0.72 | -145 | 0.73 | -170 | 0.75 | 175 | 0.77 | 165 |
| | 10 | 0.71 | -160 | 0.74 | 180 | 0.75 | 170 | 0.77 | 160 |
| | 20 | 0.73 | -170 | 0.75 | 175 | 0.77 | 165 | 0.79 | 155 |
| | 30 | 0.74 | -175 | 0.76 | 170 | 0.78 | 165 | 0.81 | 155 |
| | 40 | 0.74 | -180 | 0.76 | 165 | 0.79 | 155 | 0.81 | 145 |
| | 50 | 0.74 | 180 | 0.77 | 165 | 0.79 | 155 | 0.82 | 145 |
| 10 | 2.0 | 0.77 | -115 | 0.74 | -155 | 0.76 | -170 | 0.78 | 175 |
| | 5.0 | 0.71 | -140 | 0.72 | -170 | 0.73 | 175 | 0.75 | 165 |
| | 10 | 0.69 | -155 | 0.71 | -175 | 0.73 | 170 | 0.75 | 165 |
| | 20 | 0.69 | -165 | 0.72 | 175 | 0.74 | 165 | 0.76 | 160 |
| | 30 | 0.70 | -170 | 0.73 | 175 | 0.75 | 165 | 0.77 | 160 |
| | 40 | 0.69 | -175 | 0.72 | 165 | 0.75 | 155 | 0.78 | 145 |
| | 50 | 0.70 | -175 | 0.73 | 165 | 0.76 | 155 | 0.80 | 145 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | $\angle\phi$ | S22 | $\angle\phi$ | S22 | $\angle\phi$ | S22 | $\angle\phi$ |
| 5.0 | 2.0 | 0.66 | -50 | 0.57 | -70 | 0.57 | -95 | 0.61 | -115 |
| | 5.0 | 0.45 | -65 | 0.37 | -85 | 0.39 | -105 | 0.44 | -120 |
| | 10 | 0.33 | -80 | 0.27 | -100 | 0.30 | -115 | 0.35 | -130 |
| | 20 | 0.24 | -95 | 0.21 | -115 | 0.24 | -125 | 0.29 | -135 |
| | 30 | 0.21 | -100 | 0.18 | -120 | 0.22 | -125 | 0.28 | -135 |
| | 40 | 0.18 | -100 | 0.16 | -115 | 0.20 | -125 | 0.27 | -135 |
| | 50 | 0.17 | -95 | 0.16 | -110 | 0.21 | -120 | 0.28 | -135 |
| 10 | 2.0 | 0.71 | -45 | 0.62 | -65 | 0.62 | -85 | 0.64 | -105 |
| | 5.0 | 0.51 | -55 | 0.43 | -70 | 0.44 | -90 | 0.48 | -105 |
| | 10 | 0.37 | -60 | 0.31 | -75 | 0.33 | -95 | 0.38 | -110 |
| | 20 | 0.27 | -70 | 0.23 | -80 | 0.26 | -95 | 0.32 | -115 |
| | 30 | 0.23 | -65 | 0.21 | -80 | 0.25 | -95 | 0.31 | -110 |
| | 40 | 0.23 | -60 | 0.22 | -70 | 0.25 | -90 | 0.32 | -110 |
| | 50 | 0.24 | -50 | 0.24 | -65 | 0.28 | -90 | 0.34 | -105 |

FIGURE 6 – $S_{21}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| 5.0 | 2.0 | 3.52 | 102 | 1.97 | 70 | 1.33 | 50 | 0.99 | 35 |
| | 5.0 | 5.61 | 95 | 2.96 | 70 | 1.98 | 50 | 1.50 | 35 |
| | 10 | 6.84 | 90 | 3.55 | 70 | 2.35 | 55 | 1.78 | 40 |
| | 20 | 7.65 | 85 | 3.94 | 65 | 2.59 | 50 | 1.96 | 40 |
| | 30 | 7.93 | 85 | 4.02 | 65 | 2.63 | 50 | 1.98 | 40 |
| | 40 | 7.87 | 80 | 3.95 | 65 | 2.57 | 45 | 1.92 | 30 |
| | 50 | 7.65 | 80 | 3.86 | 60 | 2.48 | 45 | 1.86 | 30 |
| 10 | 2.0 | 3.70 | 105 | 2.12 | 75 | 1.43 | 50 | 1.07 | 35 |
| | 5.0 | 6.09 | 95 | 3.24 | 70 | 2.17 | 50 | 1.62 | 35 |
| | 10 | 7.53 | 90 | 3.91 | 70 | 2.58 | 55 | 1.96 | 40 |
| | 20 | 8.54 | 85 | 4.38 | 70 | 2.86 | 55 | 2.17 | 40 |
| | 30 | 8.79 | 85 | 4.45 | 65 | 2.92 | 50 | 2.17 | 40 |
| | 40 | 8.58 | 80 | 4.32 | 65 | 2.80 | 45 | 2.08 | 30 |
| | 50 | 8.30 | 80 | 4.15 | 60 | 2.69 | 45 | 1.98 | 30 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 500 | | 1000 | | 1500 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 5.0 | 2.0 | 0.11 | 25 | 0.11 | 5.0 | 0.10 | -5 | 0.09 | -5 |
| | 5.0 | 0.07 | 25 | 0.08 | 15 | 0.08 | 15 | 0.08 | 15 |
| | 10 | 0.05 | 25 | 0.06 | 25 | 0.07 | 30 | 0.08 | 30 |
| | 20 | 0.04 | 35 | 0.05 | 40 | 0.07 | 40 | 0.08 | 40 |
| | 30 | 0.03 | 45 | 0.05 | 45 | 0.06 | 50 | 0.08 | 45 |
| | 40 | 0.03 | 50 | 0.05 | 50 | 0.07 | 50 | 0.08 | 50 |
| | 50 | 0.03 | 55 | 0.05 | 55 | 0.06 | 50 | 0.08 | 50 |
| 10 | 2.0 | 0.09 | 25 | 0.10 | 5.0 | 0.09 | 0 | 0.08 | 0 |
| | 5.0 | 0.06 | 25 | 0.07 | 15 | 0.07 | 20 | 0.07 | 20 |
| | 10 | 0.05 | 30 | 0.06 | 30 | 0.06 | 30 | 0.07 | 35 |
| | 20 | 0.03 | 40 | 0.05 | 40 | 0.06 | 45 | 0.07 | 40 |
| | 30 | 0.03 | 40 | 0.05 | 45 | 0.06 | 47 | 0.07 | 45 |
| | 40 | 0.03 | 45 | 0.05 | 50 | 0.06 | 50 | 0.07 | 45 |
| | 50 | 0.03 | 50 | 0.04 | 50 | 0.06 | 50 | 0.07 | 50 |

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Semiconductors
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# MRF914

## Advance Information

## The RF Line

### NPN SILICON HIGH FREQUENCY TRANSISTOR

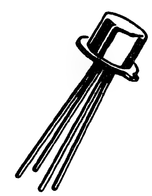
. . . designed for applications requiring high-gain, low-noise and low distortion. Also excellent for high speed switching applications.

- Low Noise Figure –
  NF = 2.0 dB (Typ) @ f = 0.5 GHz
  = 2.5 dB (Typ) @ f = 1.0 GHz
- High Power Gain –
  $G_{max}$ = 15 dB (Typ) @ f = 0.5 GHz
  = 10 dB (Typ) @ f = 1.0 GHz

$f_T$ = 4.5 GHz @ 20 mA

**HIGH FREQUENCY TRANSISTOR**

**NPN SILICON**



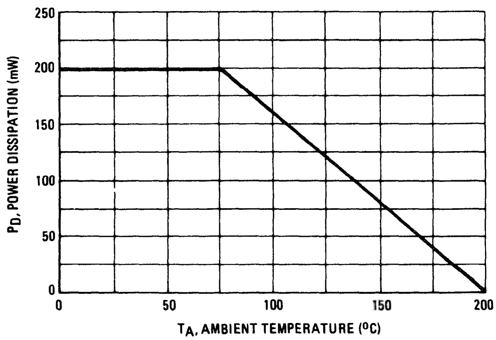
**MAXIMUM RATINGS**

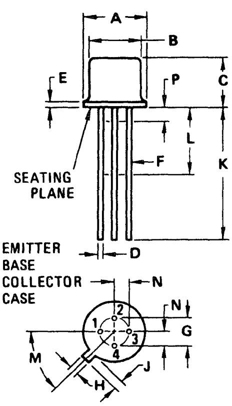
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 12 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 20 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 3.0 | Vdc |
| Collector Current – Peak | $I_C$ | 40 | mAdc |
| Total Device Dissipation @ $T_A$ = 75°C<br>Derate Above 75°C | $P_D$ | 200<br>1.6 | mW<br>mW/°C |
| Storage Temperature Range | $T_{stg}$ | -65 to +200 | °C |

**THERMAL CHARACTERISTICS**

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Ambient | $R_{\theta JA}$ | 625 | °C/W |

**FIGURE 1 – POWER DERATING**




STYLE 10
PIN 1. EMITTER
2. BASE
3. COLLECTOR
4. CASE

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 5.31 | 5.84 | 0.209 | 0.230 |
| B | 4.52 | 4.95 | 0.178 | 0.195 |
| C | 4.32 | 5.33 | 0.170 | 0.210 |
| D | 0.41 | 0.53 | 0.016 | 0.021 |
| E | – | 0.76 | – | 0.030 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.91 | 1.17 | 0.036 | 0.046 |
| J | 0.71 | 1.22 | 0.028 | 0.048 |
| K | 12.70 | – | 0.500 | – |
| L | 6.35 | – | 0.250 | – |
| M | 45° BSC | | 45° BSC | |
| N | 1.27 BSC | | 0.050 BSC | |
| P | – | 1.27 | – | 0.050 |

ALL JEDEC dimensions and notes apply

**CASE 20-03**
**TO-72**

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C = 25°C$ unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C = 1.0$ mAdc, $I_B = 0$) | $BV_{CEO}$ | 12 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C = 0.1$ mAdc, $I_E = 0$) | $BV_{CBO}$ | 20 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E = 0.1$ mAdc, $I_C = 0$) | $BV_{EBO}$ | 3.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB} = 15$ Vdc, $I_E = 0$) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C = 20$ mAdc, $V_{CE} = 10$ Vdc) | $h_{FE}$ | 30 | – | 200 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_C = 20$ mAdc, $V_{CE} = 10$ Vdc, f = 0.5 GHz) | $f_T$ | – | 4.5 | – | GHz |
| Collector-Base Capacitance ($V_{CB} = 10$ Vdc, $I_E = 0$, f = 1.0 MHz) | $C_{cb}$ | – | 0.7 | 1.0 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_C = 5.0$ mAdc, $V_{CE} = 10$ Vdc, f = 0.5 GHz) | | – | 2.0 | – | |
| ($I_C = 5.0$ mAdc, $V_{CE} = 10$ Vdc, f = 1.0 GHz) | | – | 2.5 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_C = 5.0$ mAdc, $V_{CE} = 10$ Vdc, f = 0.5 GHz) | | – | 12 | – | |
| ($I_C = 5.0$ mAdc, $V_{CE} = 10$ Vdc, f = 1.0 GHz) | | – | 7.0 | – | |
| Maximum Available Power Gain (1) | $G_{max}$ | | | | dB |
| ($I_C = 20$ mAdc, $V_{CE} = 10$ Vdc, f = 0.5 GHz) | | – | 15 | – | |
| ($I_C = 20$ mAdc, $V_{CE} = 10$ Vdc, f = 1.0 GHz) | | – | 10 | – | |

(1) $G_{max} = \dfrac{|S_{21}|^2}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$

**FIGURE 2 – POWER GAIN AND NOISE FIGURE versus FREQUENCY**

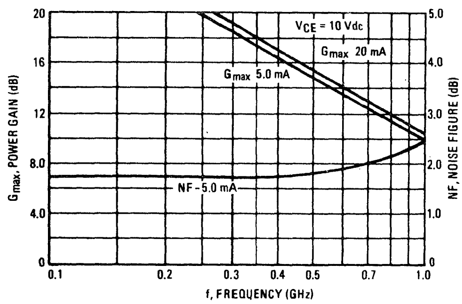



**FIGURE 3 – POWER GAIN AND NOISE FIGURE versus COLLECTOR CURRENT**

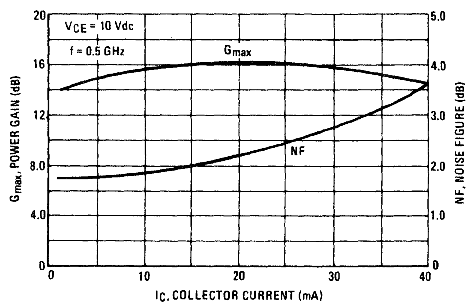


FIGURE 4 – $S_{11}$ PARAMETERS

| Frequency (MHz) | | 100 | | 300 | | 500 | | 700 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ | S11 | ∠φ |
| 5.0 | 2.0 | 0.84 | -35 | 0.57 | -80 | 0.42 | -115 | 0.34 | -140 | 0.27 | -166 |
| | 5.0 | 0.65 | -45 | 0.34 | -85 | 0.23 | -115 | 0.18 | -130 | 0.16 | -150 |
| | 10 | 0.48 | -50 | 0.32 | -85 | 0.14 | -105 | 0.12 | -115 | 0.09 | -120 |
| | 20 | 0.33 | -50 | 0.15 | -75 | 0.10 | -90 | 0.09 | -100 | 0.09 | -101 |
| | 30 | 0.27 | -50 | 0.13 | -70 | 0.09 | -85 | 0.09 | -100 | 0.09 | -101 |
| 10 | 2.0 | 0.86 | -30 | 0.59 | -75 | 0.42 | -105 | 0.34 | -130 | 0.25 | -155 |
| | 5.0 | 0.70 | -40 | 0.37 | -75 | 0.24 | -95 | 0.18 | -110 | 0.13 | -125 |
| | 10 | 0.55 | -45 | 0.26 | -70 | 0.17 | -80 | 0.14 | -90 | 0.13 | -90 |
| | 20 | 0.41 | -45 | 0.21 | -60 | 0.15 | -65 | 0.13 | -75 | 0.14 | -80 |
| | 30 | 0.36 | -45 | 0.19 | -55 | 0.14 | -65 | 0.13 | -75 | 0.13 | -80 |

FIGURE 5 – $S_{22}$ PARAMETERS

| Frequency (MHz) | | 100 | | 300 | | 500 | | 700 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ | S22 | ∠φ |
| 5.0 | 2.0 | 0.94 | -15 | 0.77 | -25 | 0.68 | -30 | 0.66 | -35 | 0.64 | -45 |
| | 5.0 | 0.85 | -20 | 0.63 | -30 | 0.57 | -30 | 0.55 | -35 | 0.55 | -45 |
| | 10 | 0.75 | -25 | 0.55 | -25 | 0.51 | -30 | 0.50 | -35 | 0.50 | -40 |
| | 20 | 0.66 | -25 | 0.50 | -25 | 0.47 | -30 | 0.47 | -35 | 0.48 | -40 |
| | 30 | 0.62 | -25 | 0.49 | -25 | 0.46 | -25 | 0.46 | -30 | 0.47 | -40 |
| 10 | 2.0 | 0.95 | -10 | 0.81 | -20 | 0.74 | -30 | 0.72 | -35 | 0.71 | -40 |
| | 5.0 | 0.87 | -15 | 0.69 | -25 | 0.64 | -25 | 0.63 | -30 | 0.63 | -40 |
| | 10 | 0.80 | -20 | 0.63 | -20 | 0.59 | -25 | 0.59 | -30 | 0.60 | -40 |
| | 20 | 0.72 | -20 | 0.59 | -20 | 0.57 | -23 | 0.57 | -30 | 0.58 | -35 |
| | 30 | 0.70 | -20 | 0.59 | -20 | 0.57 | -20 | 0.57 | -30 | 0.58 | -35 |

FIGURE 6 – $S_{21}$ PARAMETERS

| Frequency (MHz) | | 100 | | 300 | | 500 | | 700 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ mA | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ | S21 | ∠φ |
| 5.0 | 2.0 | 5.99 | 150 | 4.06 | 110 | 2.90 | 90 | 2.27 | 75 | 1.71 | 55 |
| | 5.0 | 11.38 | 135 | 5.91 | 100 | 3.90 | 80 | 2.93 | 70 | 2.17 | 55 |
| | 10 | 15.21 | 125 | 6.78 | 95 | 4.34 | 80 | 3.23 | 70 | 2.38 | 55 |
| | 20 | 17.98 | 115 | 7.27 | 90 | 4.58 | 75 | 3.40 | 65 | 2.50 | 50 |
| | 30 | 18.78 | 110 | 7.37 | 85 | 4.64 | 75 | 3.42 | 65 | 2.50 | 50 |
| 10 | 2.0 | 6.05 | 150 | 4.20 | 115 | 3.04 | 90 | 2.37 | 75 | 1.75 | 55 |
| | 5.0 | 11.46 | 135 | 6.17 | 100 | 4.06 | 85 | 3.08 | 70 | 2.26 | 55 |
| | 10 | 15.45 | 127 | 7.08 | 95 | 4.56 | 80 | 3.41 | 70 | 2.50 | 55 |
| | 20 | 18.35 | 120 | 7.57 | 90 | 4.80 | 75 | 3.58 | 65 | 2.61 | 55 |
| | 30 | 19.12 | 115 | 7.63 | 90 | 4.79 | 75 | 3.56 | 65 | 2.60 | 55 |

FIGURE 7 – $S_{12}$ PARAMETERS

| Frequency (MHz) | | 100 | | 300 | | 500 | | 700 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ (Volts) | $I_C$ (mA) | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ | S12 | ∠φ |
| 5.0 | 2.0 | 0.04 | 70 | 0.09 | 50 | 0.11 | 50 | 0.12 | 50 | 0.16 | 50 |
| | 5.0 | 0.04 | 70 | 0.07 | 60 | 0.11 | 60 | 0.14 | 60 | 0.19 | 55 |
| | 10 | 0.03 | 70 | 0.07 | 70 | 0.11 | 65 | 0.15 | 65 | 0.20 | 55 |
| | 20 | 0.03 | 75 | 0.07 | 70 | 0.12 | 70 | 0.15 | 65 | 0.21 | 55 |
| | 30 | 0.03 | 75 | 0.07 | 70 | 0.12 | 70 | 0.16 | 65 | 0.21 | 57 |
| 10 | 2.0 | 0.03 | 70 | 0.07 | 55 | 0.09 | 50 | 0.10 | 50 | 0.13 | 55 |
| | 5.0 | 0.03 | 70 | 0.06 | 60 | 0.09 | 65 | 0.12 | 60 | 0.15 | 60 |
| | 10 | 0.03 | 70 | 0.06 | 65 | 0.09 | 65 | 0.12 | 65 | 0.17 | 60 |
| | 20 | 0.03 | 75 | 0.06 | 70 | 0.09 | 70 | 0.13 | 65 | 0.18 | 60 |
| | 30 | 0.03 | 75 | 0.06 | 70 | 0.10 | 70 | 0.13 | 65 | 0.17 | 60 |

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## Advance Information

## The RF Line

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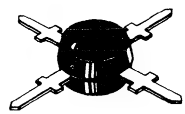
. . . designed primarily for use in low-power amplifiers to 1.0 GHz. Ideal for pagers and other battery operated systems where low power consumption is critical.

- Low Power Consumption Characterized for $I_E$ = 0.1 to 1.0 mA
- High Current-Gain — Bandwidth Product — $f_T$ = 3.0 GHz (Typ)
- Stripline Design for Optimum Performance



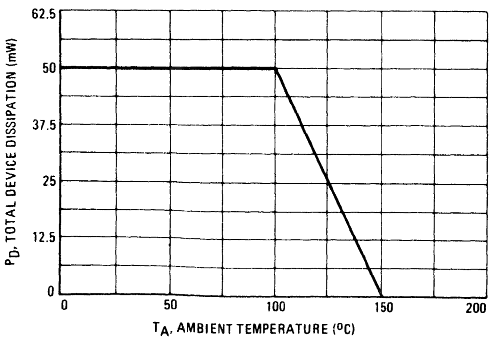
### MAXIMUM RATINGS

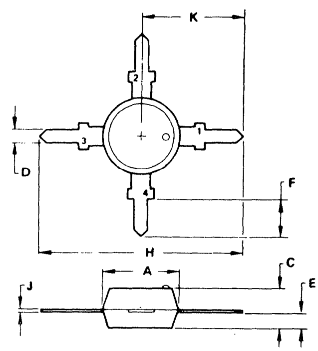
| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector-Emitter Voltage | $V_{CEO}$ | 5.0 | Vdc |
| Collector-Base Voltage | $V_{CBO}$ | 10 | Vdc |
| Emitter-Base Voltage | $V_{EBO}$ | 2.0 | Vdc |
| Collector Current — Peak | $I_C$ | 5.0 | mAdc |
| Total Device Dissipation @ $T_A$ = 100°C<br>Derate Above 100°C | $P_D$ | 50<br>1.0 | mW<br>mW/°C |
| Junction Temperature | $T_J$ | +150 | °C |
| Storage Temperature Range | $T_{stg}$ | -65 to +150 | °C |

### THERMAL CHARACTERISTICS

| Characteristic | Symbol | Max | Unit |
|---|---|---|---|
| Thermal Resistance, Junction to Ambient | $R_{\theta JA}$ | 500 | °C/W |

FIGURE 1 — POWER DERATING




STYLE 1:
PIN 1. COLLECTOR
2. EMITTER
3. BASE
4. EMITTER

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | – | 4.78 | – | 0.188 |
| C | – | 3.05 | – | 0.120 |
| D | 0.64 | 0.89 | 0.025 | 0.035 |
| E | 0.97 | 1.22 | 0.038 | 0.048 |
| F | 2.21 | 2.46 | 0.087 | 0.097 |
| H | 12.40 | 12.90 | 0.488 | 0.508 |
| J | 0.10 | 0.15 | 0.004 | 0.006 |
| K | 6.20 | 6.45 | 0.244 | 0.254 |

CASE 302-01

This is advance information and specifications are subject to change without notice.

**ELECTRICAL CHARACTERISTICS** ($T_C$ = 25°C unless otherwise noted).

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | |
| Collector-Emitter Breakdown Voltage ($I_C$ = 0.1 mAdc, $I_B$ = 0) | $BV_{CEO}$ | 5.0 | – | – | Vdc |
| Collector-Base Breakdown Voltage ($I_C$ = 0.01 mAdc, $I_E$ = 0) | $BV_{CBO}$ | 10 | – | – | Vdc |
| Emitter-Base Breakdown Voltage ($I_E$ = 0.1 mAdc, $I_C$ = 0) | $BV_{EBO}$ | 2.0 | – | – | Vdc |
| Collector Cutoff Current ($V_{CB}$ = 5.0 Vdc, $I_E$ = 0) | $I_{CBO}$ | – | – | 50 | nAdc |
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain ($I_C$ = 0.25 mAdc, $V_{CE}$ = 1.0 Vdc) | $h_{FE}$ | 30 | – | 150 | – |
| **DYNAMIC CHARACTERISTICS** | | | | | |
| Current-Gain Bandwidth Product ($I_E$ = 1.0 mAdc, $V_{CE}$ = 1.0 Vdc, f = 1.0 GHz) | $f_T$ | – | 3.0 | – | GHz |
| Collector-Base Capacitance ($V_{CB}$ = 1.0 Vdc, $I_E$ = 0, f = 1.0 MHz) | $C_{cb}$ | – | 0.35 | 0.5 | pF |
| **FUNCTIONAL TESTS** | | | | | |
| Noise Figure | NF | | | | dB |
| ($I_E$ = 0.25 mAdc, $V_{CE}$ = 1.0 Vdc, f = 0.5 GHz) | | – | 3.8 | – | |
| ($I_E$ = 0.25 mAdc, $V_{CE}$ = 1.0 Vdc, f = 1.0 GHz) | | – | 4.3 | – | |
| Power Gain at Optimum Noise Figure | $G_{NF}$ | | | | dB |
| ($I_E$ = 0.25 mAdc, $V_{CE}$ = 1.0 Vdc, f = 0.5 GHz) | | – | 16 | – | |
| ($I_E$ = 0.25 mAdc, $V_{CE}$ = 1.0 Vdc, f = 1.0 GHz) | | – | 10 | – | |
| Transducer Power Gain | $G_T$ | | | | dB |
| ($I_E$ = 0.5 mAdc, $V_{CE}$ = 1.0 Vdc, f = 0.5 GHz) | | – | 18 | – | |
| ($I_E$ = 0.5 mAdc, $V_{CE}$ = 1.0 Vdc, f = 1.0 GHz) | | – | 12 | – | |

**FIGURE 2 — TRANSDUCER POWER GAIN AND NOISE FIGURE versus FREQUENCY**

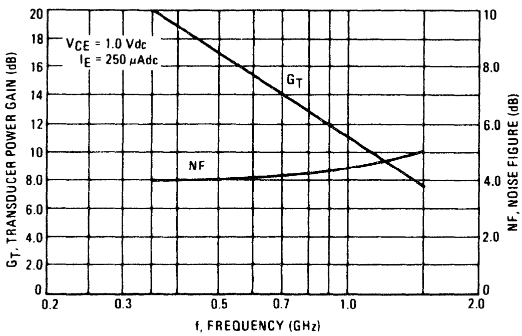
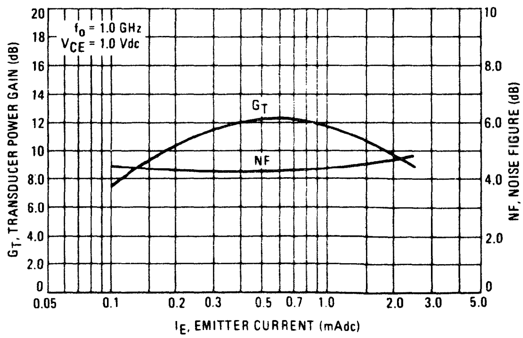



**FIGURE 3 — TRANSDUCER POWER GAIN AND NOISE FIGURE versus EMITTER CURRENT**



# RF SMALL SIGNAL DESIGN USING TWO-PART PARAMETERS

Prepared By:
**Roy Hejhall**

## INTRODUCTION

Design of the solid-state, small-signal RF amplifier using two-port parameters is a systematic, mathematical procedure, with an exact solution (free from approximation) available for the complete design problem. The only sources of error in the final design are parameter variations resulting from transistor parameter distributions and strays in the physical circuit. Parameter distributions result from limits in measurement and random variations among identically designed transistors.

The purpose of this paper is to provide, in a single working reference, the important relationships necessary for the complete solution of the RF small-signal design problem using two-port parameters.

The major portion of the report presents design equations in terms of admittance parameters. A section on design with scattering parameters is also included.

This paper is based on work by Linvill[1], Stern[2], and others. Those who may wish to consider the derivations of some of the expressions should refer to the bibliography.

This report assumes that the reader is familiar with the two-port parameter method of describing a linear active network. Several references are available on this subject. 1, 2, 5, 6, 8, 9.

It has also been assumed that a suitable transistor or other active device for the task at hand has been selected, and that two-port parameters are available for the frequency and bias point which will be used. Device selection will not be covered as a separate topic in this report; rather, a thorough understanding of the material in the report should provide the designer with the tools he needs to select transistors for a particular small-signal application.

The equations given in the text of this report are applicable to the common-emitter, common-base, or common-collector configuration, if the applicable set of parameters (common-emitter, common-base, or common-collector parameters) is used. Equations for the conversion of the admittance or hybrid parameters of any configuration to either of the other two configurations of the same parameter set are given in the appendix.

While directed primarily toward circuit design with conventional bipolar transistors, two-port network theory has the advantage of being applicable to any linear active network (LAN). The same design approach and equations may therefore be used with field effect transistors integrated circuits[7], or any other device which may be described as a linear active two-port network.

Finally, various parameter interrelationships and other data are given in the Appendix.

## GENERAL DESIGN CONSIDERATIONS

Design of the RF small-signal tuned amplifier is usually based on a requirement for a specified power gain at a given frequency. Other design goals may include bandwidth, stability, input-output isolation, and low noise performance. After a basic circuit type is selected, the applicable design equations can be solved.

Circuits may be categorized according to feedback (neutralization, unilateralization, or no feedback), and matching at transistor terminals (circuit admittances either matched or mismatched to transistor input and output admittances). Each of these circuit categories will be discussed, including the applicable design equations and the considerations leading to the selection of a particular configuration.

## STABILITY

A major factor in the overall design is the potential stability of the transistor. This may be determined by computing the Linvill stability factor[1] C using the following expression:†

$$C = \frac{|y_{12}\, y_{21}|}{2g_{11}\, g_{22} - \mathrm{Re}\,(y_{12}y_{21})} \qquad (1)$$

When C is less than 1, the transistor is unconditionally stable. When C is greater than 1, the transistor is potentially unstable.

The C factor is a test for stability under a hypothetical worst case condition; that is, with both input and output transistor terminals open circuited. With no external feedback, an unconditionally stable transistor will not oscillate with any combination of source and load. If a transistor is potentially unstable, certain source and load combinations will produce oscillations.

Although the C factor may be used to determine the potential stability of a transistor, the conditions of open circuited source and load which are assumed in the C factor test are not applicable to a practical amplifier.

†Re $(Y_{12}Y_{21})$ = Real part of $(Y_{12}Y_{21})$

Consequently it is also desirable to compute the relative stability of actual amplifier circuits, and Stern[2] has defined a stability factor k for this purpose. The k factor is similar to the C factor except that it also takes into account finite source and load admittances connected to the transistor. The expression for k is:

$$k = \frac{2\,(g_{11} + G_s)\,(g_{22} + G_L)}{|y_{12}y_{21}| + \mathrm{Re}\,(y_{12}y_{21})} \qquad (2)$$

If k is greater than one, the circuit will be stable. If k is less than one, the circuit will be potentially unstable and will very likely oscillate at some frequency.

Note that the C factor simply predicts potential stability of a transistor with an open circuited source and load, while the k factor provides a stability computation for a specific circuit.

Stability considerations will be discussed further in the descriptions of each basic circuit type to follow.

## GENERAL DESIGN EQUATIONS

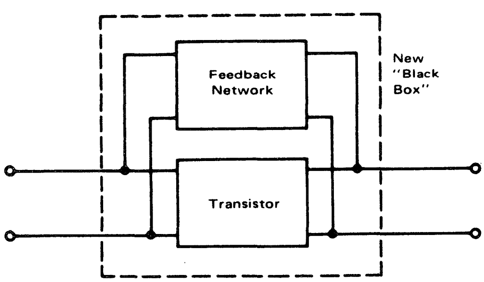
There are a number of design equations which are applicable to most types of amplifiers. These equations will be discussed first. Descriptions of specific amplifier types will then follow, and each will contain additional design equations applicable to that particular amplifier.

## POWER GAIN

The general expression for power gain is:

$$G = \frac{|y_{21}|^2\,\mathrm{Re}\,(Y_L)}{|Y_L + y_{22}|^2\,\mathrm{Re}\,\left(y_{11} - \frac{y_{12}y_{21}}{y_{22} + Y_L}\right)} \qquad (3)$$

Equation 3 applies to circuits with no external feedback. It can also be used with circuits which have external feedback if the composite y parameters of both the transistor and the feedback network are substituted for the transistor y parameters in the equation. The composite y parameters are determined by considering the transistor and the feedback network to be two "black boxes" in parallel:




For example, the above combination of transistor and feedback network may be characterized as a single "black box" by the following equations:†

$$\begin{aligned} y_{11c} &= y_{11t} + y_{11f} \\ y_{12c} &= y_{12t} + y_{12f} \\ y_{21c} &= y_{21t} + y_{21f} \\ y_{22c} &= y_{22t} + y_{22f} \end{aligned} \qquad (4)$$

Where:

$y_{11c}, y_{12c}, y_{21c}, y_{22c}$ are the composite y parameters of the parallel combination of transistor and feedback network.

$y_{11t}, y_{12t}, y_{21t}, y_{22t}$ are the y parameters of the transistor.

$y_{11f}, y_{12f}, y_{21f}, y_{22f}$ are the y parameters of the feedback network.

Note that, since this approach treats the transistor and feedback network combination as a single "black box" with $y_{11c}, y_{12c}, y_{21c}$, and $y_{22c}$ as its y parameters, the composite y parameters may therefore be substituted in any of the design equations applicable to a linear, active two-port analysis.

The neutralized and unilateralized amplifiers are special cases of this general concept, and equations associated with those special cases will be given later.

Equation 3 provides a solution for power gain of the linear active network (transistor) only. Input and output networks are considered to be part of the source and load, respectively. Two important points should therefore be kept in mind:

(1) Power gain computed from equation 3 will not take into account network losses. Input network loss reduces power delivered to the transistor. Power lost in the output network is computed as useful power output, since the load admittance $Y_L$ is the combination of the output network and its load.

(2) Power gain is independent of source admittance. An input mismatch results in less input power being delivered to the transistor. Accordingly, note that equation 3 does not contain the term $Y_S$.

The power gain of a transistor together with its associated input and output networks may be computed by measuring the input and output network losses, and subtracting them from the power gain computed with equation 3.

In some cases it may be desirable to include the effects of input matching in power gain computations. A convenient term is transducer gain $G_T$, defined as output power delivered to a load by the transistor, divided by the

†Refer to Seshu and Balabanian, "Linear Network Analysis," John Wiley and Sons, 1959, P321

maximum input power available from the source.

The equation for transducer gain is:

$$G_T = \frac{4 \, Re\,(Y_s)\, Re\,(Y_L)\, |y_{21}|^2}{|(y_{11} + Y_s)(y_{22} + Y_L) - y_{12}y_{21}|^2} \qquad (5)$$

In this equation, $Y_L$ is the composite transistor load admittance-composed of both output network and its load, and $Y_S$ is the composite transistor source admittance-composed of both input network and its source. Therefore, transducer gain includes the effects of the degree of admittance match at the transistor input terminals but does not take into account input and output network losses.

As in equation 3, the composite y parameters of a transistor feedback network combination may be substituted for the transistor y parameters when such a combination is used.

The Maximum Available Gain MAG is an often used transistor figure-of-merit. The MAG is the theoretical power gain of a transistor with its reverse transfer admittance $y_{12}$ set equal to zero, and its source and load admittances conjugately matched to $y_{11}$ and $y_{22}$, respectively.

If $y_{12} = 0$, the transistor exhibits an input admittance equal to $y_{11}$ and an output admittance equal to $y_{22}$.† The equation for MAG is, therefore, obtained by solving the general power gain expression, equation 3, with the conditions

$$y_{12} = 0$$

$$y_L = y_{22}^*$$

$$\text{and } y_s = y_{11}^*$$

where * denotes conjugate

which yields:

$$MAG = \frac{|y_{21}|^2}{4 \, Re\,(y_{11})\, Re\,(y_{22})} \qquad (6)$$

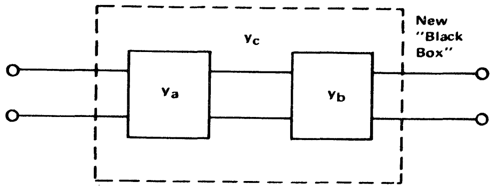
MAG is a figure of merit only, since it is physically impossible to reduce $y_{12}$ to zero without changing the other parameters of the transistor. An external feedback network may be used to achieve a composite $y_{12}$ of zero, but then the other composite parameters will also be modified according to the relationships given in the discussion of the composite transistor – feedback network "black box."

†Obtained by solving the equations for transistor $Y_{IN}$ and $Y_{OUT}$ with $y_{12}$ equal to zero. These equations are given later in the report.

## CASCADED LAN'S

Design calculations for cascaded LAN's may be performed by first computing composite two-port parameters as was done in the case of the parallel LAN's.

For the following cascaded LAN's




The composite y parameters are:

$$y_{11c} = y_{11a} - \frac{y_{12a}\,y_{21a}}{y_{22a} + y_{11b}}$$

$$y_{22c} = y_{22b} - \frac{y_{12b}\,y_{21b}}{y_{22a} + y_{11b}} \qquad (7)$$

$$y_{21c} = -\frac{y_{21a}\,y_{21b}}{y_{22a} + y_{11b}}$$

$$y_{12c} = -\frac{y_{12a}\,y_{12b}}{y_{22a} + y_{11b}}$$

where $y_{11c}$, $y_{22c}$, $y_{21c}$, $y_{12c}$ are the composite y parameters of the cascaded LAN's.

## TRANSISTOR INPUT AND OUTPUT ADMITTANCES

The expression for the input admittance of a transistor is:

$$Y_{IN} = y_{11} - \frac{y_{12}\,y_{21}}{y_{22} + Y_L} \qquad (8)$$

The expression for the output admittance of a transistor is:

$$Y_{OUT} = y_{22} - \frac{y_{12}\,y_{21}}{y_{11} + Y_s} \qquad (9)$$

When the feedback parameter $y_{12}$ is not zero, $Y_{IN}$ is dependent on load admittance and $Y_{OUT}$ is dependent on source admittance.

## AMPLIFIER STABILITY

One of the major considerations in RF amplifier design is stability. The stability of a final design can be assured by including stability computations and considering stability in all design decisions relating to feedback and transistor source and load admittances.

The potential stability of the transistor should first be computed using equation 1.

The various alternatives concerning input – output matching and neutralization – unilateralization will now be discussed for both the unconditionally stable transistor and the potentially unstable transistor.

## THE UNCONDITIONALLY STABLE TRANSISTOR

When the Linvill stability factor of the transistor as determined by equation 1 is less than one, the transistor is unconditionally stable. Oscillations will not occur using any combination of source and load admittances without external feedback. Stability is therefore eliminated as a factor in the remainder of the design, and complete freedom is possible with regard to matching and neutralization to optimize the amplifier for other performance requirements.

## AMPLIFIERS WITHOUT FEEDBACK

The amplifier with no feedback is a logical choice for the unconditionally stable transistor in many applications since it may offer the advantages of fewer components and a simple tuning procedure.

Source and load admittances may be selected for maximum gain and/or any number of other requirements. Power gain and transducer gain may be computed using equations 3 and 5, respectively; input and output admittances may be computed using equations 8 and 9, respectively.

The amplifier stability factor may be computed using equation 2. While amplifier stability was assured from the beginning by the use of an unconditionally stable transistor, the designer may still wish to perform this computation to provide some insight into danger of instability under adverse environmental conditions, source and load variations, etc.

## $G_{max}$

$G_{max}$, the highest transducer gain possible without external feedback, forms a special case of the no feedback amplifier.

The source and load admittances required to achieve $G_{max}$ may be computed from the following:

$$G_s = \frac{1}{2\,\mathrm{Re}(y_{22})} \left\{ \left[ 2\,\mathrm{Re}(y_{11})\,\mathrm{Re}(y_{22}) - \mathrm{Re}(y_{12}y_{21}) \right]^2 - \left| y_{12}y_{21} \right|^2 \right\}^{\frac{1}{2}} \qquad (10)$$

$$B_s = -\,\mathrm{Im}(y_{11}) + \frac{\mathrm{Im}(y_{21}y_{12})}{2\,\mathrm{Re}(y_{22})} \qquad (11)$$

$$G_L = \frac{1}{2\,\mathrm{Re}(y_{11})} \left\{ \left[ 2\,\mathrm{Re}(y_{11})\,\mathrm{Re}(y_{22}) - \mathrm{Re}(y_{12}y_{21}) \right]^2 - \left| y_{12}y_{21} \right|^2 \right\}^{\frac{1}{2}} \qquad (12)$$

$$B_L = -\,\mathrm{Im}(y_{22}) + \frac{\mathrm{Im}(y_{21}y_{12})}{2\,\mathrm{Re}(y_{11})} \qquad (13)$$

Therefore, if the maximum possible power gain without feedback is desired for an amplifier, equations 10, 11 12, and 13 are used to compute $Y_s$ and $Y_L$.

The magnitude of $G_{max}$ may be computed from the following expressions:

$$G_{max} = \frac{\left| y_{21} \right|^2}{2\,\mathrm{Re}(y_{11})\,\mathrm{Re}(y_{22}) - \mathrm{Re}(y_{12}y_{21}) + \left\{ \left[ 2\,\mathrm{Re}(y_{11})\,\mathrm{Re}(y_{22}) - \mathrm{Re}(y_{12}y_{21}) \right]^2 - \left| y_{12}y_{21} \right|^2 \right\}^{\frac{1}{2}}} \qquad (14)$$

Equations 10, 11, 12, and 13 can be obtained by differentiating equation 5 with respect to $G_S$, $B_S$, $G_L$, and $B_L$, and setting the four derivatives equal to zero. The $G_S$, $B_S$, $G_L$, and $B_L$ thus computed can then be substituted in equation 5 to obtain the expression for $G_{max}$, equation 14.

## THE LINVILL METHOD

The amplifier without feedback design problem may also be solved graphically using a technique developed by J. G. Linvill.† Linvill's technique is very useful for a certain class of problems. Since it is so fully discussed in many good references, we will not go into it further here. An advantage of the Linvill technique is that it provides a reasonably rapid graphic solution relating gain, bandwidth, and stability. A disadvantage is its scope of usefulness, since the standard Linvill solution applies only to an amplifier with no external feedback and the $Y_S$ conjugately matched to the transistor input admittance, $Y_{IN}$.

## THE UNILATERALIZED AMPLIFIER

Unilateralization consists of employing an external feedback network to achieve a composite $y_{12}$ of zero.

While unilateralization is perhaps most often used to achieve stability with a potentially unstable transistor, other circuit considerations may also warrant the use of unilateralization with the unconditionally stable transistor. For example, the input-output isolation afforded by unilateralization may be desirable in a particular design.

Design equations for the unilateralized case are obtained by first computing the composite y parameters of the transistor – feedback network combination and then substituting the composite parameters in the general equations.

Referring to the discussion on composite y parameters and setting up the basic condition that $y_{12c}$ must equal zero, the other composite y parameters can be computed. Assuming that a passive feedback network is being used, then

$$y_{11f} = y_{22f} = -y_{12f} = -y_{21f}.$$

$$\text{and since } y_{12c} = 0,\ y_{12t} + y_{12f} = 0$$

$$\text{then } y_{12t} = -y_{12f},$$

$$\text{and } y_{12t} = -y_{12f} = y_{11f} = y_{22f} = -y_{21f}$$

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† See reference 4 in the bibliography.

Substituting the above results in equations 4 yields the following:

$$y_{11c} = y_{11t} + y_{12t}$$

$$y_{22c} = y_{22t} + y_{12t}$$

$$y_{12c} = y_{12t} - y_{12t} = 0$$

$$y_{21c} = y_{21t} - y_{12t}$$

Substituting these complete y parameters in equations 8, 9, 3, 7, and 5 respectively, yields equations 15, 16, 17 18, and 19 respectively for the unilateralized case.

Unilateralized input admittance

$$Y_{IN} = y_{11} + y_{12} \tag{15}$$

Unilateralized output admittance

$$Y_{OUT} = y_{22} + y_{12} \tag{16}$$

Unilateralized power gain, general expression:

$$G_{PU} = \frac{|y_{21} - y_{12}|^2 \, Re(Y_L)}{|Y_L + y_{22} + y_{12}|^2 \, Re(y_{11})} \tag{17}$$

Unilateralized power gain with $Y_L$ conjugately matched to $Y_{OUT}$:

$$G_U = \frac{|y_{21} - y_{12}|^2}{4 \, Re(y_{11} + y_{12}) \, Re(y_{22} + y_{12})} \tag{18}$$

Unilateralized transducer gain:

$$G_{TU} = \frac{4 \, Re(Y_s) \, Re(Y_L) \, |y_{21} - y_{12}|^2}{|(y_{11} + y_{12} + Y_s)(y_{22} + y_{12} + Y_L)|^2} \tag{19}$$

Note that equations 15, 16, 17, 18 and 19, are given entirely in terms of the transistor y parameters, not those of the feedback network or the composite.

Another benefit of unilateralization is input – output isolation. As can be seen in equations 15 and 16, $Y_{IN}$ is completely independent of $Y_L$, and $Y_{OUT}$ is similarly independent of $Y_s$. In a practical sense, this means that in a single or multi-stage amplifier using unilateralized stages, tuning of any one network will not affect tuning in other parts of the circuit. Thus, the troublesome task of having to re-peak an entire amplifier following a change in tuning at a single point can be eliminated.

## NEUTRALIZATION

Neutralization consists of employing a feedback network to reduce $y_{12}$ to some value other than zero. Neutralization is generally used for the same purposes as unilateralization, but provides something less than the ideal cancellation of the transistor feedback parameter which unilateralization achieves. A typical example of neutralization might be a feedback network which provides a composite $b_{12}$ of zero while having only a negligible effect on the transistor $g_{12}$.

The equations for a particular neutralized case would be developed in the same manner as those for the unilateralized case. Since there are an infinite number of possibilities, no specific equations will be given here.

This completes the discussion of design with the unconditionally stable transistor. The potentially unstable transistor will now be considered.

## THE POTENTIALLY UNSTABLE TRANSISTOR

When the Linvill stability factor of the transistor as determined by equation 1 is greater than one, the transistor is potentially unstable. Certain combinations of source and load admittances will cause oscillations if no feedback is used. In designing with the potentially unstable transistor, steps must be taken to insure that the amplifier will be stable.

Stability is usually achieved by one or both of two methods:

(1) Using a feedback network which reduces the composite $y_{12}$ to a value which insures stability.

(2) Choosing a source and load admittance combination which provides stability.

A discussion of these basic methods is given below.

## USING FEEDBACK TO ACHIEVE STABILITY

Either unilateralization or neutralization may be used to achieve stability. If unilateralization is used, the transistor-feedback network combination will be unconditionally stable. This may be verified by computing the Linvill stability factor of the combination. Since $y_{12c} = 0$, the numerator in equation 1 would be zero.

With stability thus assured, the remainder of the design may then be done to satisfy other requirements placed on the amplifier. After unilateralization has converted the potentially unstable transistor to an unconditionally stable combination, all other aspects of the design are identical to the unilateralized case with the unconditionally stable transistor. Power gains and input and output admittances may be computed using equations 15 through 19.

If neutralization is used to achieve stability, the Linvill stability factor can be used to compute the potential stability of any transistor – neutralization network combination. Since in this case $y_{12c} \neq 0$, C will have a value other than zero.

After unconditional stability of the transistor-neutralization network combination has been achieved, the design may then be completed by treating the combination as an unconditionally stable transistor, and proceeding with the case of the unconditionally stable transistor in an amplifier without feedback. Power gains, input and output admittances, and the circuit stability factor may be computed by using the composite parameters of the combination in equations 2, 3, 5, 8, and 9.

## STABILITY WITHOUT FEEDBACK

A stable design with the potentially unstable transistor is possible without external feedback by proper choice of

souce and load admittances. This can be seen by inspection of equation 2; $G_S$ and/or $G_L$ can be made large enough to yield a stable circuit regardless of the degree of potential instability of the transistor.

This suggests a relatively simple way to achieve a stable design with a potentially unstable transistor. A circuit stability factor k is selected, and equation 2 is used to arrive at values of $G_S$ and $G_L$ which will provide the desired k. In achieving a particular circuit stability factor, the designer may choose any of the following combinations of matching or mismatching of $G_S$ and $G_L$ to the transistor input and output conductances, respectively:

(1) $G_S$ matched and $G_L$ mismatched
(2) $G_L$ matched and $G_S$ mismatched
(3) Both $G_S$ and $G_L$ mismatched

Often a decision on which combination to use will be dictated by other performance requirements or practical considerations.

Once $G_S$ and $G_L$ have been chosen, the remainder of the design may be completed using the relationships which apply to the amplifier without feedback. Power gain and input and output admittances may be computed using equations 3, 5, 8, and 9.

Although the above procedure may be adequate in many cases, a more systematic method of source and load admittance determination is desirable for designs which demand maximum power gain per degree of circuit stability. Stern has analyzed this problem and developed equations for computing the conductance and susceptance of both $Y_S$ and $Y_L$ for maximum power gain for a particular circuit stability factor.[2,4] These equations are given here:

$$G_s = \sqrt{\frac{k\left[\left|y_{12}y_{21}\right| + Re(y_{12}y_{21})\right]}{2}} \cdot \sqrt{\frac{g_{11}}{g_{22}}} - g_{11} \qquad (20)$$

$$G_L = \sqrt{\frac{k\left[\left|y_{12}y_{21}\right| + Re(y_{12}y_{21})\right]}{2}} \cdot \sqrt{\frac{g_{22}}{g_{11}}} - g_{22} \qquad (21)$$

$$B_s = \frac{(G_s + g_{11})\ Zo}{\sqrt{k\left[\left|y_{12}y_{21}\right| + Re(y_{12}y_{21})\right]}} - b_{11} \qquad (22)$$

$$B_L = \frac{(G_L + g_{22})\ Zo}{\sqrt{k\left[\left|y_{12}y_{21}\right| + Re(y_{12}y_{21})\right]}} - b_{22} \qquad (23)$$

Where,

$$Z = \frac{(B_s + b_{11})(G_L + g_{22}) + (B_L + b_{22})\ k(L + M)/2(G_L + g_{22})}{\sqrt{k\ (L + M)}} \qquad (24)$$

$$L = \left|y_{12}y_{21}\right| \qquad (25)$$

$$M = Re(y_{12}y_{21}) \qquad (26)$$

Defining D as the demoninator in equation 5 yields:

$$D = \frac{Z^4}{4} + \frac{\left[k(L + M) + 2M\right] Z^2}{2} - 2NZ\sqrt{k(L + M)} + A^2 + N^2 \qquad (27)$$

where,

$$A = \frac{k(L + M)}{2} - M, \qquad (28)$$

$$N = Im(y_{12}y_{21}), \qquad (29)$$

and,

$Z_O$ = that real value of Z which results in the smallest minimum of D, found by setting,

$$\frac{dD}{dZ} = Z^3 + \left[k(L + M) + 2M\right] Z - 2N\sqrt{k(L + M)} \qquad (30)$$

equal to zero.

Computation of $Y_S$ and $Y_L$ using equations 20 through 30 is a bit tedious to be done very frequently, and this may have discouraged wide usage of the complete Stern solution. However, examination of Stern's work suggests some interesting shortcuts:

(A) COMPUTATION OF $G_S$ AND $G_L$ ONLY, USING EQUATIONS 20 AND 21. If a value equal to $-b_{22}$ is then chosen for $B_L$, the resulting $Y_L$ will be very close to the true $Y_L$ for maximum gain. The transistor $Y_{IN}$ can then be computed from $Y_L$ using equation 8, and $B_S$ can be set equal to $-Im(Y_{IN})$.

Computation of $B_S$ and $B_L$ comprise by far the more complex portion of the Stern solution. This alternate method therefore permits the designer to closely approximate the exact Stern solution for $Y_S$ and $Y_L$ while avoiding that portion of the computations which are the most complex and time consuming. Further, the circuit can be designed with tuning adjustments for varying $B_S$ and $B_L$, thereby creating the possibility of experimentally achieving the true $B_S$ and $B_L$ for maximum gain as accurately as if all the Stern equations had been solved.

(B) MISMATCHING $G_S$ TO $g_{11}$ AND $G_L$ TO $g_{22}$ BY AN EQUAL RATIO YIELDS A TRUE STERN SOLUTION FOR $G_S$ AND $G_L$. This can be derived from equations 20 and 21, which lead to the following result:

$$\frac{G_L}{g_{22}} = \frac{G_s}{g_{11}} \qquad (31)$$

If a mismatch ratio, R, is defined as follows,

$$R = \frac{G_L}{g_{22}} = \frac{G_s}{g_{11}} \qquad (32)$$

then R may be computed for any particular circuit stability factor using the equation:

$$(1 + R)^2 = k\left[\frac{\left|y_{21}y_{12}\right| + Re(y_{12}y_{21})}{2\ g_{11}\ g_{22}}\right] \qquad (33)$$

Equation 33 was derived from equation 2 and 32. Having thus determined R, $G_S$ and $G_L$ can be quickly found using equation 32.

$B_S$ and $B_L$ can then be determined in the

manner described above in alternate method (A).

This alternate method may be advantageous if source and load admittances and power gains for several different values of k are desired. Once the R for a particular k has been determined, the R for any other k may be quickly found from the equation

$$\frac{(1 + R_1)^2}{(1 + R_2)^2} = \frac{k_1}{k_2} \tag{34}$$

where $R_1$ and $R_2$ are values of R corresponding to $k_1$ and $k_2$, respectively.

(C) COMPUTER DESIGN. The complete Stern design problem may be programmed into a computer. Power gain, circuit stability factor, $Y_S$ and $Y_L$ can be obtained from the computer for any value of k. MAG, $G_U$, and the Linvill stability factor of the transistor may also be included in the program.

After employing either the complete Stern solution or an alternate method to obtain $Y_S$ and $Y_L$ for the potentially unstable transistor in an amplifier without feedback, power gains and input and output admittances may be obtained using equations 3, 5, 8, and 9.

## SENSITIVITY

In all but the unilateralized amplifier, $Y_{IN}$ is a function of load admittance. Thus $Y_{IN}$ changes with output circuit tuning, and this can be troublesome. Consequently, it is sometimes desirable to compute the extent of variation of $Y_{IN}$ with changes in $Y_L$. A term, sensitivity $\delta$, has been defined to provide a measure of this characteristic, and is equal to per cent change in $Y_{IN}$ divided by per cent change in $Y_L$. The equation for sensitivity is:

$$\delta = \left|\frac{Y_L}{y_{22} + Y_L}\right| \cdot \left|\frac{g_{11}}{y_{11}}\right| \cdot \frac{K}{\left|\dfrac{y_{22} + Y_L}{g_{22}} + \dfrac{g_{11}}{y_{11}} K e^{j\theta}\right|} \tag{35}$$

where,

$$K = \left|\frac{y_{21}\, y_{12}}{g_{11}\, g_{22}}\right|$$

$$\theta = \arg\,(-y_{12}y_{21})$$

$$K e^{j\theta} = K\,(\cos\theta + j\,\sin\theta)$$

A more complete discussion of sensitivity is given in reference 5.

## DESIGN WITH SCATTERING PARAMETERS

Scattering, or s parameters have greatly increased in popularity since the late 1960's, largely due to the appearance of sophisticated new equipment for performing s parameter measurements.

A summary of s parameter design equations is given below.

Power gain:

$$G = \frac{|s_{21}|^2 (1 - |\Gamma_L|^2)}{(1 - |s_{11}|^2) + |\Gamma_L|^2 (|s_{22}|^2 - |\Delta s|^2) - 2\,\mathrm{Re}\,(\Gamma_L N)} \tag{36}$$

$$\Delta s = s_{11}s_{22} - s_{12}s_{21}$$

$$N = s_{22} - D s^*_{11}$$

Transducer gain:

$$G_T = \frac{|s_{21}|^2 (1 - |\Gamma_S|^2)(1 - |\Gamma_L|^2)}{|(1 - s_{11}\Gamma_S)(1 - s_{22}\Gamma_L) - s_{12}s_{21}\Gamma_L\Gamma_S|^2} \tag{37}$$

Input reflection coefficient:

$$s'_{11} = s_{11} + \frac{s_{12}s_{21}\Gamma_L}{1 - s_{22}\Gamma_L} \tag{38}$$

Output reflection coefficient:

$$s'_{22} = s_{22} + \frac{s_{12}s_{21}\Gamma_S}{1 - s_{11}\Gamma_S} \tag{39}$$

Linvill stability factor:

$$C = K^{-1}$$

$$K = \frac{1 + |\Delta s|^2 - |s_{11}|^2 - |s_{22}|^2}{2|s_{12}s_{21}|} \tag{40}$$

$$\Delta s = s_{11}s_{22} - s_{12}s_{21}$$

Equation 40 which gives K, the reciprocal of C, is presented in this form because it is the s parameter stability expression most often seen in the literature. K in equation 40 must not be confused with Stern stability factor k given in equation 2.

Maximum unneutralized transducer gain, unconditionally stable LAN:

$$G_{max} = \left|\frac{s_{21}}{s_{12}}(K \pm \sqrt{K^2 - 1})\right| \tag{41}$$

$$K = C^{-1}$$

C = Linvill Stability Factor

Source and load reflection coefficients for a conjugate match of the unconditionally stable LAN in an amplifier without feedback:

$$\Gamma_{mS} = M^* \left[\frac{B_1 \pm \sqrt{B_1^2 - 4|M|^2}}{2|M|^2}\right] \tag{42}$$

$$\Gamma_{mL} = N^* \left[\frac{B_2 \pm \sqrt{B_2^2 - 4|N|^2}}{2|N|^2}\right] \tag{43}$$

Where $B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta s|^2$

$$B_2 = 1 + |s_{22}|^2 - |s_{11}|^2 - |\Delta s|^2$$

$$M = s_{11} - (\Delta s)(s_{22}{}^*)$$

$$N = s_{22} - (\Delta s)(s_{11}{}^*)$$

A more comprehensive treatment of amplifier design with s parameters is given in references 6, 8, and 9.

One cautionary note is in order.

Several papers have been published on the subject of simplifying the s parameter design procedure by making the assumption that the reverse transfer parameter, $s_{12}$, is equal to zero. This procedure totally ignores the entire

problem of amplifier stability.

Modern high gain solid-state RF devices will readily oscillate under a wide variety of circuit conditions. Stability problems are encountered even with extremely low feedback devices such as Linear IC's and dual gate MOSFETS. Therefore, amplifier design calculations which do not include device and circuit feedback are only an approximation which will yield either an inaccurate solution or possibly even an oscillator when the design is tested in the laboratory. Reference 10 provides more detail on the shortcomings of this procedure, including an amplifier design example which did turn out to be an oscillator.

## SUMMARY OF DESIGN PROCEDURE

A summary of the amplifier design procedure using two-port parameters is given below.

1. Determine the potential instability of the active device.
2. If the device is not unconditionally stable, decide on a course of action to insure circuit stability.
3. Determine whether or not feedback is to be used.
4. Determine source and load admittances.
5. Design appropriate networks to provide the desired source and load admittances.

***Stability*** (Steps 1 and 2 above)

A stability computation for the worst case conditions of open circuit source and load is provided by Linvill's stability factor C. If the C factor indicates unconditional stability, no combination of passive terminations can cause oscillations.

Stability calculations should include the total feedback of the amplifier. In the case of extremely low feedback devices such as dual gate MOSFET's and Linear IC's, external circuit feedback often eclipses the internal device feedback. In such a case, the designer should measure the external circuit feedback and include it in the design calculations. To accomplish this, see the earlier section of this note on the composite parameters of two-port LAN's in parallel.

If the device is unconditionally stable, the design may proceed to fulfill other objectives without fear of oscillations. If the device is potentially unstable, steps must be taken to prevent oscillations in the final design. Stability is achieved by proper selection of source and load admittances, by the use of feedback, or both.

***Feedback*** (Step 3)

Feedback may be employed in the tuned high frequency amplifier to achieve stability, input-output isolation, or to alter the gain and terminal admittances of the active device. A decision to employ feedback would be based on whether or not its use was the optimum way to accomplish one of the foregoing objectives in a particular application.

If feedback is employed, the device parameters may be modified to include the feedback network in accordance with standard two-port network theory. The remainder of the design may then proceed by treating the transistor-feedback network combination as a single, new two-port linear active network.

***Source and Load Admittances*** (Step 4)

Source and load admittance determination is dependent upon gain and stability considerations, together with practical circuit limitations.

If the device is either unconditionally stable itself or has been made stable with feedback, stability need not be a major factor in the determination of source and load. If the device is potentially unstable and feedback is not employed, then a source and load which will guarantee a certain degree of circuit stability must be used. Also, it is a good idea to check the circuit stability factor during this step even when an unconditionally stable device is used.

Finally, practical limitations in matching networks and components may also play an important part of source and load admittance determination.

***Network Design*** (Step 5)

The final step consists of network synthesis to achieve the desired source and load admittances computed in step 4.

Sometimes, it will be difficult to achieve a desired source and load due to tuning range limitations, excess network losses, component limitations, etc. In such cases, the source and load admittances will be a compromise between desired performance and practical limitations.

## SUMMARY

The small signal amplifier performance of a transistor is completely described by two-port admittance parameters. Based on these parameters, equations for computing the stability, gain, and optimum source and load admittances for the unilateralized, neutralized, and no-feedback amplifier cases have been discussed.

The unconditionally stable transistor will not oscillate with any combination of source and load admittances, and circuits using a stable transistor may be optimized for other performance requirements without fear of oscillations.

The potentially unstable transistor requires that steps be taken to guarantee a stable design. Stability is usually achieved by unilateralization, neutralization, or selection of source and load admittances which result in a stable amplifier.

Unilateralization and neutralization reduce the composite reverse transfer admittance. They may be used to achieve stability, input – output isolation, or both.

Maximum power gain per degree of circuit stability without feedback may be achieved using Stern's equations.

The degree of input – output isolation is described by the term sensitivity, which makes it possible to compute changes in input admittance for any change in load admittance.

The theory and design equations in this report are applicable to any linear active device which may be characterized as a two-port network. Therefore, the term "transistor" used herein refers generally to all such devices, including FETs and integrated circuits.

## BIBLIOGRAPHY


1. "Transistors and Active Circuits," by Linvill and Gibbons, McGraw-Hill, 1961.
2. "Stability and Power Gain of Tuned Transistor Amplifiers," by Arthur P. Stern, Proc. IRE, March, 1957.
3. "High-Gain, High-Frequency Amplifiers," by Peter M. Norris, Electro-Technology, January, 1966.
4. "Linvill Technique Speeds High Frequency Amplifier Design," by John Lauchner and Marvin Silverstein, Electronic Design, April, 12, 1966.
5. "The Design of Alignable Transistor Amplifiers," by J. F. Gibbons, Stanford University Technical Report No. 106, May 7, 1956.
6. "Circuit Design and Characterization of Transistors by Means of Three-Part Scattering Parameters" by George E. Bodway, the Microwave Journal, May, 1968.
7. "A High Gain Integrated Circuit RF-IF Amplifier with Wide Range AGC", Motorola Semiconductor Products, Inc. Application Note 513.
8. "S Parameter Design", Hewlett-Packard Company, Palo Alto, California, Application Note 154.
9. "S Parameters", Hewlett-Packard Company, Palo Alto, California, Application Note 95.
10. "Staying Stable with S Parameters", by Roy Hejhall, Motorola Monitor, Vol. 7, No. 2.


## GLOSSARY

$C$ = Linvill's stability factor
$k$ = Stern's stability factor
$G_S$ = Real part of the source admittance
$G_L$ = Real part of the load admittance
$B_S$ = Imaginary part of the source admittance
$B_L$ = Imaginary part of the load admittance
$g_{11}$ = Real part of $y_{11}$
$g_{22}$ = Real part of $y_{22}$
$G$ = Generalized power gain
$Y_L$ = Complex load admittance
$Y_S$ = Complex source admittance
$G_T$ = Transducer gain
MAG = Maximum available gain
* = Conjugate
$Y_{IN}$ = Input admittance
$Y_{OUT}$ = Output admittance
$G_{max}$ = Maximum gain without feedback
$G_U$ = Unilateralized gain
$G_{TU}$ = Unilateralized transducer gain
$\delta$ = Sensitivity
$s'_{11}$ = Input reflection coefficient
$s'_{22}$ = Output reflection coefficient
$\Gamma_L$ = Load reflection coefficient
$\Gamma_S$ = Source reflection coefficient
$K$ = Scattering parameter stability factor

## APPENDIX I

A. Conversions among parameter types for y, z, h, and g parameters.

h to y

$$y_{11} = \frac{1}{h_{11}} \quad y_{12} = \frac{-h_{12}}{h_{11}} \quad y_{21} = \frac{h_{21}}{h_{11}} \quad y_{22} = \frac{\Delta h}{h_{11}}$$

where $\Delta h = h_{11} h_{22} - h_{12} h_{21}$

y to h

$$h_{11} = \frac{1}{y_{11}} \quad h_{12} = \frac{-y_{12}}{y_{11}} \quad h_{21} = \frac{y_{21}}{y_{11}} \quad h_{22} = \frac{\Delta y}{y_{11}}$$

where $\Delta y = y_{11} y_{22} - y_{12} y_{21}$

h to z

$$z_{11} = \frac{\Delta h}{h_{22}} \quad z_{12} = \frac{h_{12}}{h_{22}} \quad z_{21} = \frac{-h_{21}}{h_{22}} \quad z_{22} = \frac{1}{h_{22}}$$

z to h

$$h_{11} = \frac{\Delta z}{z_{22}} \quad h_{12} = \frac{z_{12}}{z_{22}} \quad h_{21} = \frac{-z_{21}}{z_{22}} \quad h_{22} = \frac{1}{z_{22}}$$

where $\Delta z = z_{11} z_{22} - z_{12} z_{21}$

h to g

$$g_{11} = \frac{h_{22}}{\Delta h} \qquad g_{12} = \frac{-h_{12}}{\Delta h} \qquad g_{21} = \frac{-h_{21}}{\Delta h}, \qquad g_{22} = \frac{h_{11}}{\Delta h}$$

where $\Delta h = h_{11} h_{22} - h_{12} h_{21}$

g to h

$$h_{11} = \frac{g_{22}}{\Delta g} \qquad h_{12} = \frac{-g_{12}}{\Delta g} \qquad h_{21} = \frac{-g_{21}}{\Delta g} \qquad h_{22} = \frac{g_{11}}{\Delta g}$$

where $\Delta g = g_{11} g_{22} - g_{12} g_{21}$

z to y

$$y_{11} = \frac{z_{22}}{\Delta z} \qquad y_{12} = \frac{-z_{12}}{\Delta z} \qquad y_{21} = \frac{-z_{21}}{\Delta z} \qquad y_{22} = \frac{z_{11}}{\Delta z}$$

where $\Delta z = z_{11} z_{22} - z_{12} z_{21}$

y to z

$$z_{11} = \frac{y_{22}}{\Delta y} \qquad z_{12} = \frac{-y_{12}}{\Delta y} \qquad z_{21} = \frac{-y_{21}}{\Delta y} \qquad z_{22} = \frac{y_{11}}{\Delta y}$$

where $\Delta y = y_{11} y_{22} - y_{12} y_{21}$

z to g

$$g_{11} = \frac{1}{z_{11}} \qquad g_{12} = \frac{-z_{12}}{z_{11}} \qquad g_{21} = \frac{z_{21}}{z_{11}} \qquad g_{22} = \frac{\Delta z}{z_{11}}$$

where $\Delta z = z_{11} z_{22} - z_{12} z_{21}$

g to z

$$z_{11} = \frac{1}{g_{11}} \qquad z_{12} = \frac{-g_{12}}{g_{11}} \qquad z_{21} = \frac{g_{21}}{g_{11}} \qquad z_{22} = \frac{\Delta g}{g_{11}}$$

where $\Delta g = g_{11} g_{22} - g_{12} g_{21}$

g to y

$$y_{11} = \frac{\Delta g}{g_{22}} \qquad y_{12} = \frac{g_{12}}{g_{22}} \qquad y_{21} = \frac{-g_{21}}{g_{22}} \qquad y_{22} = \frac{1}{g_{22}}$$

where $\Delta g = g_{11} g_{22} - g_{12} g_{21}$

y to g

$$g_{11} = \frac{\Delta y}{y_{22}} \qquad g_{12} = \frac{y_{12}}{y_{22}} \qquad g_{21} = \frac{-y_{21}}{y_{22}} \qquad g_{22} = \frac{1}{y_{22}}$$

where $\Delta y = y_{11} y_{22} - y_{12} y_{21}$

B. Conversions among common emitter, common base, and common collector parameters of the same type for y, and h parameters.

Common emitter y parameters in terms of common base and common collector y parameters.

$$y_{11e} = y_{11b} + y_{12b} + y_{21b} + y_{22b} = y_{11c}$$
$$y_{12e} = -(y_{12b} + y_{22b}) = -(y_{11c} + y_{12c})$$
$$y_{21e} = -(y_{21b} + y_{22b}) = -(y_{11c} + y_{21c})$$
$$y_{22e} = y_{22b} = y_{11c} + y_{12c} + y_{21c} + y_{22c}$$

Common base y parameters in terms of common emitter and common collector y parameters.

$$y_{11b} = y_{11e} + y_{12e} + y_{21e} + y_{22e} = y_{22c}$$
$$y_{12b} = -(y_{12e} + y_{22e}) = -(y_{21c} + y_{22c})$$
$$y_{21b} = -(y_{21e} + y_{22e}) = -(y_{12c} + y_{22c})$$
$$y_{22b} = y_{22e} = y_{11c} + y_{12c} + y_{21c} + y_{22c}$$

Common collector y parameters in terms of common emitter and common base y parameters.

$$y_{11c} = y_{11e} = y_{11b} + y_{12b} + y_{21b} + y_{22b}$$
$$y_{12c} = -(y_{11e} + y_{12e}) = -(y_{11b} + y_{21b})$$
$$y_{21c} = -(y_{11e} + y_{21e}) = -(y_{11b} + y_{12b})$$
$$y_{22c} = y_{11e} + y_{12e} + y_{21e} + y_{22e} = y_{11b}$$

Common emitter h parameters in terms of common base and common collector h parameters.

$$h_{11e} = \frac{h_{11b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{h_{11b}}{1 + h_{21b}} = h_{11c}$$

$$h_{12e} = \frac{h_{11b} h_{22b} - h_{12b}(1+h_{21b})}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{h_{11b} h_{22b}}{1 + h_{21b}} - h_{12b} = 1-h_{12c}$$

$$h_{21e} = \frac{-h_{21b}(1-h_{12b}) - h_{22b} h_{11b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{-h_{21b}}{1 + h_{21b}} = -(1 + h_{21c})$$

$$h_{22e} = \frac{h_{22b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{h_{22b}}{1 + h_{21b}} = h_{22c}$$

Common has h parameters in terms of common emitter and common collector h parameters.

$$h_{11b} = \frac{h_{11e}}{(1 + h_{21e})(1-h_{12e}) + h_{11e} h_{22e}} \approx \frac{h_{11e}}{1 + h_{21e}}$$

$$= \frac{h_{11c}}{h_{11c} h_{22c} - h_{21c} h_{12c}} \approx \frac{-h_{11c}}{h_{21c}}$$

$$h_{12b} = \frac{h_{11e} h_{22e} - h_{12e}(1 + h_{21e})}{(1 + h_{21e})(1-h_{12e}) + h_{11e} h_{22e}} \approx \frac{h_{11e} h_{22e}}{1 + h_{21e}} - h_{12e}$$

$$= \frac{h_{21c}(1-h_{12c}) + h_{11c} h_{22c}}{h_{11c} h_{22c} - h_{21c} h_{12c}} \approx (h_{12c} - 1) - \frac{h_{11c} h_{22c}}{h_{21c}}$$

$$h_{21b} = \frac{-h_{21e}(1-h_{12e}) - h_{11e} h_{22e}}{(1 + h_{21e})(1-h_{12e}) + h_{11e} h_{22e}} \approx \frac{-h_{21e}}{1 + h_{21e}}$$

$$= \frac{h_{12c}(1 + h_{21c}) - h_{11c} h_{22c}}{h_{11c} h_{22c} - h_{21c} h_{12c}} \approx \frac{-(1 + h_{21c})}{h_{21c}}$$

$$h_{22b} = \frac{h_{22e}}{(1 + h_{21e})(1-h_{12e}) + h_{11e} h_{22e}} \approx \frac{h_{22e}}{1 + h_{21e}}$$

$$= \frac{h_{22c}}{h_{11c} h_{22c} - h_{21c} h_{12c}} \approx \frac{h_{22c}}{h_{21c}}$$

Common collector h parameters in terms of common base and common emitter h parameters.

$$h_{11c} = \frac{h_{11b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{h_{11b}}{1 + h_{21b}} = h_{11e}$$

$$h_{12c} = \frac{1 + h_{21b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx 1 = 1-h_{12e}$$

$$h_{21c} = \frac{h_{12b} - 1}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{-1}{1 + h_{21b}} = -(1 + h_{21e})$$

$$h_{22c} = \frac{h_{22b}}{(1 + h_{21b})(1-h_{12b}) + h_{22b} h_{11b}} \approx \frac{h_{22b}}{1 + h_{21b}} = h_{22e}$$

Expressions for voltage gain, current gain, input impedance, and output impedance in terms of y, z, h, and g parameters.

Voltage Gain

$$A_V = \frac{z_{21} Z_L}{\Delta z + z_{11} Z_L} = \frac{-y_{21}}{y_{22} + Y_L} = \frac{-h_{21} Z_L}{h_{11} + \Delta h Z_L} = \frac{g_{21} Z_L}{g_{22} + Z_L}$$

$$= \frac{S_{21}(1 + \Gamma_L)}{(1 - S_{22}\Gamma_L)(1 + S'_{11})}$$

Current Gain

$$A_I = \frac{-z_{21}}{z_{22} + Z_L} = \frac{-y_{21} Y_L}{\Delta y + y_{11} Y_L} = \frac{h_{21} Y_L}{h_{22} + Y_L} = \frac{-g_{21}}{\Delta g + g_{11} Z_L}$$

Input Impedance

$$Z_{IN} = \frac{\Delta z + z_{11} Z_L}{z_{22} + Z_L} = \frac{y_{22} + Y_L}{\Delta y + y_{11} Y_L} = \frac{\Delta h + h_{11} Y_L}{h_{22} + Y_L}$$

$$= \frac{g_{22} + Z_L}{\Delta g + g_{11} Z_L}$$

Output Impedance

$$Z_{OUT} = \frac{\Delta z + z_{22} Z_s}{z_{11} + Z_s} = \frac{y_{11} + Y_s}{\Delta y + y_{22} Y_s} = \frac{h_{11} + Z_s}{\Delta h + h_{22} Z_s}$$

$$= \frac{\Delta g + g_{22} Y_s}{g_{11} + Y_s}$$

Conversion between y parameters and s (scattering) parameters:

$$s_{11} = \frac{(1-y_{11})(1+y_{22}) + y_{12} y_{21}}{(1+y_{11})(1+y_{22}) - y_{12} y_{21}} \dagger$$

$$s_{12} = \frac{-2y_{12}}{(1+y_{11})(1+y_{22}) - y_{12} y_{21}} \dagger$$

$$s_{21} = \frac{-2y_{21}}{(1+y_{11})(1+y_{22}) - y_{12} y_{21}} \dagger$$

$$s_{22} = \frac{(1+y_{11})(1-y_{22}) + y_{21} y_{12}}{(1+y_{11})(1+y_{22}) - y_{12} y_{21}} \dagger$$

$$y_{11} = \left[\frac{(1+s_{22})(1-s_{11}) + s_{12} s_{21}}{(1+s_{11})(1+s_{22}) - s_{12} s_{21}}\right] \frac{1}{Z_o}$$

$$y_{12} = \left[\frac{-2s_{12}}{(1+s_{11})(1+s_{22}) - s_{12} s_{21}}\right] \frac{1}{Z_o}$$

$$y_{21} = \left[\frac{-2s_{21}}{(1+s_{11})(1+s_{22}) - s_{12} s_{21}}\right] \frac{1}{Z_o}$$

$$y_{22} = \left[\frac{(1+s_{11})(1-s_{22}) + s_{12} s_{21}}{(1+s_{22})(1+s_{11}) - s_{12} s_{21}}\right] \frac{1}{Z_o}$$

where $Z_O$= the characteristic impedance of the transmission lines used in the scattering parameter system, usually 50 ohms.

Conversion between h parameters and s parameters:

$$s_{11} = \frac{(h_{11}-1)(h_{22}+1) - h_{12} h_{21}}{(h_{11}+1)(h_{22}+1) - h_{12} h_{21}} \dagger\dagger$$

$$s_{12} = \frac{2h_{12}}{(h_{11}+1)(h_{22}+1) - h_{12} h_{21}} \dagger\dagger$$

$$s_{21} = \frac{-2h_{21}}{(h_{11}+1)(h_{22}+1) - h_{12} h_{21}} \dagger\dagger$$

$$s_{22} = \frac{(1+h_{11})(1-h_{22}) + h_{12} h_{21}}{(h_{11}+1)(h_{22}+1) - h_{12} h_{21}} \dagger\dagger$$

$$h_{11} = \left[\frac{(1+s_{11})(1+s_{22}) - s_{12} s_{21}}{(1-s_{11})(1+s_{22}) + s_{12} s_{21}}\right] Z_o$$

$$h_{12} = \frac{2s_{12}}{(1-s_{11})(1+s_{22}) + s_{12}s_{21}}$$

$$h_{21} = \frac{-2s_{21}}{(1-s_{11})(1+s_{22}) + s_{12}s_{21}}$$

$$h_{22} = \left[\frac{(1-s_{22})(1-s_{11}) - s_{12}s_{21}}{(1-s_{11})(1+s_{22}) + s_{12}s_{21}}\right] \frac{1}{Z_o}$$

†In converting from y to s parameters, the y parameters must first be multiplied by $Z_O$, and then substituted in the equations for conversion to s parameters.

††In converting from h to s parameters, the h parameters must first be normalized to $Z_O$ in the following manner and then substituted in the equations for conversion to s parameters:

| Parameter | To Normalize |
|---|---|
| $h_{11}$ | divide by $Z_O$ |
| $h_{12}$ | use as is |
| $h_{21}$ | use as is |
| $h_{22}$ | multiply by $Z_O$ |

Conversion between z parameters and s parameters:

$$Z_{11} = \left[\frac{(1 + S_{11})(1 - S_{22}) + S_{12}S_{21}}{(1 - S_{11})(1 - S_{22}) - S_{12}S_{21}}\right] Z_o$$

$$Z_{12} = \left[\frac{2S_{12}}{(1 - S_{11})(1 - S_{22}) - S_{12}S_{21}}\right] Z_o$$

$$Z_{21} = \left[\frac{2S_{21}}{(1 - S_{11})(1 - S_{22}) - S_{12}S_{21}}\right] Z_o$$

$$Z_{22} = \left[\frac{(1 + S_{22})(1 - S_{11}) + S_{12}S_{21}}{(1 - S_{11})(1 - S_{22}) - S_{12}S_{21}}\right] Z_o$$

$$S_{11} = \frac{(Z_{11} - 1)(Z_{22} + 1) - Z_{12}Z_{21}}{(Z_{11} + 1)(Z_{22} + 1) - Z_{12}Z_{21}} \quad †††$$

$$S_{12} = \frac{2Z_{12}}{(Z_{11} + 1)(Z_{22} + 1) - Z_{12}Z_{21}} \quad †††$$

$$S_{21} = \frac{2Z_{21}}{(Z_{11} + 1)(Z_{22} + 1) - Z_{12}Z_{21}} \quad †††$$

$$S_{22} = \frac{(Z_{11} + 1)(Z_{22} - 1) - Z_{12}Z_{21}}{(Z_{11} + 1)(Z_{22} + 1) - Z_{12}Z_{21}} \quad †††$$

†††In converting from z to s parameters, the z parameters must first be divided by $Z_O$, and then substituted in the equations for conversion to s parameters.

# UHF AMPLIFIERS DESIGN USING DATA SHEET DESIGN CURVES

## INTRODUCTION

The design of UHF amplifiers usually involves a particular set of device parameters of which h, y, and s parameters are probably the most familiar. These parameters are commonly used to determine device loading (input and output) admittances for particular gain and stability criteria. The design procedure for determining gain and stability usually involves a mathematical solution, a graphical approach, or a combination of both.

This report describes a design technique for the unneutralized case whereby the device loading admittances are taken directly from device design curves. An example is given of how these design parameters are used to design a single stage 1 GHz microstrip amplifier and predicted results are compared to actual measured values. Practical circuit construction techniques are also discussed for the benefit of readers unfamiliar with microstrip techniques.

## STABILITY CONSIDERATIONS

Two very important methods[1] for expressing stability involve Linvill's stability factor "C" and Stern's stability factor "k". The first deals primarily with the device since an open termination is assumed on both the input and output and is formulated:

$$C = \frac{|y_{12}y_{12}|}{2g_{11}g_{22} - \mathrm{Re}(y_{12}y_{21})}.$$

If "C" is greater than 1, the transistor is potentially unstable. However, if C is less than 1, the transistor is unconditionally stable. The C factor versus frequency for the common base and common emitter configurations (2N4957) are shown in Figures 10 and 17 respectively.

The second method is primarily circuit oriented and is used to compute the relative stability of an actual amplifier circuit for the particular source and load terminations used. If "k" is greater than 1, the circuit is stable. If "k" is less than 1 the circuit is potentially unstable

Stern has developed equations for calculating the input and output loading admittances for maximum power gain with a particular stability factor, k. These values of input and output admittances in conjunction with the device parameters can then be used to calculate the transducer gain.[1]

$$k = \frac{2(g_{11}+G_s)(g_{22}+G_L)}{|y_{12}y_{21}| + \mathrm{Re}(y_{12}y_{21})}$$

$$G_s = \sqrt{\frac{k[|y_{12}y_{21}| + \mathrm{Re}(y_{12}y_{21})]}{2}} \cdot \sqrt{\frac{g_{11}}{g_{22}}} - g_{11}$$

$$G_L = \sqrt{\frac{k[|y_{12}y_{21}| + \mathrm{Re}(y_{12}y_{21})]}{2}} \cdot \sqrt{\frac{g_{22}}{g_{11}}} - g_{22}$$

$$B_s = \frac{(G_s + g_{11})Z_o}{\sqrt{k[|y_{12}y_{21}| + \mathrm{Re}\, y_{12}y_{21}]}} - b_{11}$$

$$B_L = \frac{(G_L + g_{22})Z_o}{\sqrt{k[|y_{12}y_{21}| + \mathrm{Re}(y_{12}y_{21})]}} - b_{22}$$

Where,

$$Z = \frac{(B_s + b_{11})(G_L + g_{22}) + (B_L + b_{22})\,k(L+M)/2(G_L + g_{22})}{\sqrt{k(L+M)}}$$

$$L = |y_{12}y_{21}|$$

$$M = \mathrm{Re}(y_{12}y_{21})$$

Defining D as the denominator in $G_T$ expression yields:

$$D = \frac{Z^4}{4} + \frac{[k(L+M) + 2M]\,Z^2}{2} - 2NZ\sqrt{k(L+M)} + A^2 + N^2$$

where, $A = \frac{k(L+M)}{2} - M,$

$N = \mathrm{Im}(y_{12}y_{21}),$

and,

$Z_o$ = that real value of Z which results in the smallest minimum of D, found by setting,

$$\frac{dD}{dZ} = Z^3 + [k(L+M) + 2M]\,Z - 2N\sqrt{k(L+M)}.$$

equal to zero.

$$G_T = \frac{4\,\mathrm{Re}(Y_s)\,\mathrm{Re}(Y_L)\,|y_{21}|^2}{|(y_{11}+Y_s)(y_{22}+Y_L) - y_{12}y_{21}|^2}$$

| | | |
|---|---|---|
| k | = | Stern's stability factor |
| $G_s$ | = | Real part of the source admittance |
| $G_L$ | = | Real part of the load admittance |
| $B_s$ | = | Imaginary part of the source admittance |
| $B_L$ | = | Imaginary part of the load admittance |
| $g_{11}$ | = | Real part of $y_{11}$ |
| $g_{22}$ | = | Real part of $y_{22}$ |
| $Y_L$ | = | Complex load admittance |
| $Y_s$ | = | Complex source admittance |
| $G_T$ | = | Transducer gain |
| $Y_{IN}$ | = | Input admittance |
| $Y_{OUT}$ | = | Output admittance |
| $G_{max}$ | = | Maximum gain without feedback |

Computer solutions of these equations for various values of k versus frequency have been plotted in Appendix I for the 2N4957. These curves include common-base (Figures 10 through 16) and common-emitter (Figures 17 through 22).

From these curves, the designer can determine the input and output loading admittances for maximum power gain at a particular circuit stability. In addition, the transducer power gain under these conditions can also be determined. Thus the designer, rather than reading s or y parameters from a curve and using this information to design an amplifier, has all the design equations solved and presented in convenient, computer-derived design curves.

The following example demonstrates how these curves can be utilized in the design of a 1 GHz amplifier using the 2N4957. In addition, a second example is shown to demonstrate the special case where input admittance is determined primarily by noise figure considerations rather than by maximum power gain.

### 1 GHz AMPLIFIER DESIGN

A preliminary investigation of stability and power gain, common-emitter and common-base, can be quickly made from the design curves. For instance, the unilateralized gain (Figure 8) at 1 GHz is approximately 15 dB for either the common-emitter or common-base configuration. Also, the C factor for the common-base configuration (Figure 10) is greater than one and indicates potential device instability. However, the C factor for the common-emitter configuration (Figure 17) is less than one and indicates unconditional device stability.

Figures 16 and 22 are key curves that show transducer power gain for the common base and common emitter configuration respectively. Assuming a circuit stability factor of 4*, power gain is approximately 15 dB, common-base. Although the common-emitter curve is not extended to 1 GHz (since this is a region of unconditional stability) power gain for k = 4 would be obviously much less than 15 dB.

Using the common base configuration with k = 4, the required input and output admittance for maximum power gain can be determined directly from Figures 11 through 16.

For instance, the real part of the output admittance can be read from either Figure 11 or 12. Figure 12 is an expanded version of Figure 11 and is intended to facilitate lower frequency use. The imaginary portion of the output admittance is shown in Figure 13. Figures 14 and 15 show the real and imaginary portions of the input admittance respectively. The resultant input and output admittances are shown in Figure 1 and are summarized:

Conditions: (2N4957)

$V_{CE}$ = 10 V
$I_C$ = 2 mA
f = 1 GHz
$G_T$ = 15 dB
k = 4

Input admittance = 69.5 mmhos +j27.1 mmhos
Output admittance = 1.53 mmhos -j7.46 mmhos

It becomes apparent that the emitter must "see" an admittance of 69.5 mmhos shunted by a susceptance of +j27.1 mmhos. The latter, in terms of a lumped constant element, would be a lossless capacitor. Likewise, the collector would be required to see an admittance of 1.53 mmhos shunted by -j7.46 mmhos. The latter, in terms of a lumped-constant element, would be a lossless coil. This loading will result in a stability factor, k, of 4 and a power gain of 15 dB, the maximum power gain possible for k = 4. This loading does not include stray capacitance. If stray capacitance is assumed to be 1 pF, the actual load is 1.53 mmhos -j13.5 mmhos (see Figure 1).

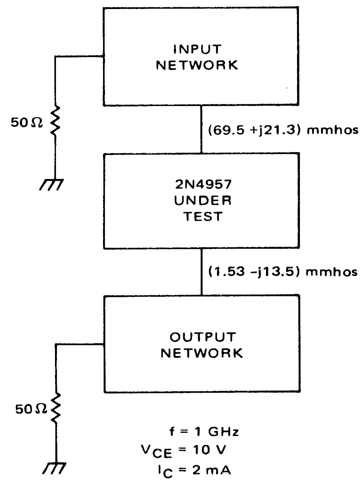


**FIGURE 1 — COMMON BASE INPUT AND OUTPUT ADMITTANCES INCLUDING STRAY CAPACITANCE**

To facilitate instrumentation, both the source and load impedance will be 50 ohms. This admittance level must be transformed to the required device loading admittance. Micro strip techniques provide a convenient method of achieving this transformation without circuit reproducibility and component loss problems that are common with many lumped constant circuits at this frequency.

The Smith Chart is a convenient design tool for solving transmission line problems of this type. Since space does not permit, familiarity with this chart will be assumed.

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*For the purpose of this report a stability factor of 4 is chosen. Values of k less than 4 may not prove to be advantageous from the standpoint of regeneration and parameter spread.

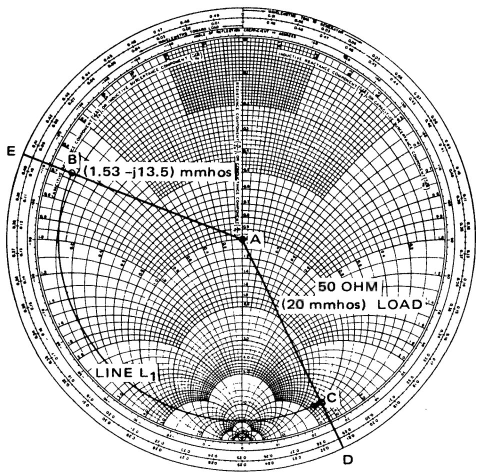


**FIGURE 2 – OUTPUT NETWORK DESIGN**

Starting with the output circuit, both the 50 ohm (20 mmhos) load and the desired collector admittance are plotted on the Smith Chart (see Figure 2). As a starting point, a characteristic admittance of 20 mmhos will be assumed. First, the 20 mmho load is plotted (point A, Figure 2), then point B is plotted (1.53 mmhos -j13.5 mmhos).

Although many different methods exist for transforming point A to point B (see Figure 2), a direct, and as it turns out, practical approach is that shown in Figure 3. This circuit uses $C_1$ in parallel with $R_L$ to vary the SWR of point A (Figure 2) to point C. Since point C has the same SWR as point B, a line $L_1$ with an electrical length equal to $0.405\lambda_2$ (point E) minus $0.214\lambda$ (point D) will complete the transformation. Collector tuning is available with component $C_2$. This variable capacitor provides the difference between the assumed stray capacitance and the actual circuit stray capacitance.

The required SWR could have been realized by using an inductor in place of $C_1$. However, an inductor would have either forced the bias feed-point to be changed to the collector lead or necessitated a dc- isolated coil. Although this is readily attainable using transmission line techniques, the variable component $C_1$ is more convenient. A typical curve of Q versus capacitance for ($C_1$) is shown in Figure 4.

The output bias is fed through a 4000 ohm resistor rather than an RF choke. The resultant 8 volt drop across this resistor is easier to contend with than the circuit instabilities sometimes associated with RF chokes.

The same procedure is followed in designing the input network (see Figure 5). Again, a stray capacitance of 1 pF is assumed. Thus, the actual input loading becomes 69.5 mmhos +j21.3 mmhos. First, the 20 mmho load is plotted (see Point T, Figure 6). Next, point W is plotted (69.5 mmhos +j21.3 mmhos). Adjusting the SWR with $C_3$ (point V) allows a transmission line of length $L_2$ to transform the admittance at point V to the desired level at the base (point W).

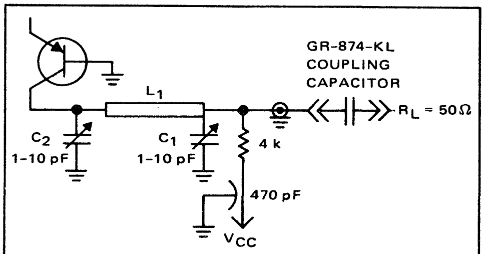


**FIGURE 3 – OUTPUT NETWORK**

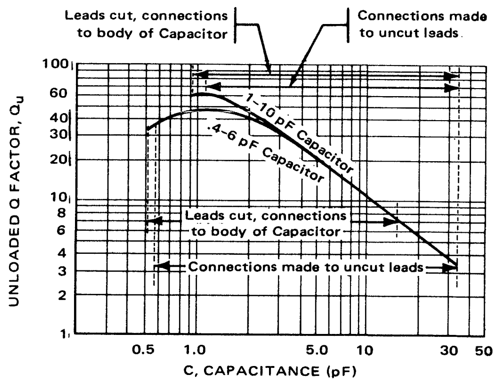


**FIGURE 4 – Q versus CAPACITANCE FOR $C_1$ @ 1 GHz**

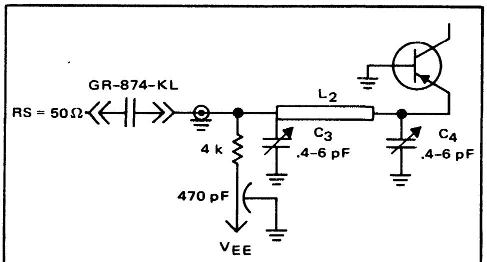


**FIGURE 5 – INPUT NETWORK**

## CIRCUIT CONSTRUCTION

The transmission line lengths $L_1$ and $L_2$ are readily transferred to micro-strip lengths once the wavelength and line-width are known. Hopefully, this information is available from the manufacturer, but if not, it must be measured before the design can be completed. The laminate used for this application required a line-width of approximately 0.16 inches for a 20 mmho characteristic admittance. This value proved adequate both from a realizable design solution on the Smith Chart and also from a practicable circuit construction standpoint.

The actual laminate thickness depends to a large extent on the desired characteristic impedance and the frequency of operation The line thickness for a 50 ohm line is approximately 0.16 inch for a 1/16 inch laminate and approximately 0.035 inch for the same laminate 1/64 inch thick. As the intended frequency of operation is increased, the line width becomes a larger percentage of the line length.[4] Higher ratios of line width to length may result in undesirable modes of operation. Decreasing the laminate thickness results in a smaller line width for the same characteristic (assuming TEM operation) and a smaller line width to length ratio.

The dielectric constant for the material used was 2.6. The actual wavelength in the laminate is:

$$\lambda\,(\text{actual}) = \frac{\lambda\,(\text{air})}{\sqrt{2.6}} = \frac{11.8 \text{ inches}}{\sqrt{2.6}} = 7.34 \text{ inches}$$

Since $L_1 = 0.191\lambda$,

The physical length of $L_1$ is 1.4 inches

Correspondingly, $L_2$ is $0.062\lambda$ or 0.455 inches.

It should be pointed out that the actual wavelength[3] for this laminate is somewhat larger than that calculated from the dielectric constant. A careful measurement[4] of wavelength versus characteristic impedance (line width) demonstrates this phenomena. The slight increase in wavelength (6%) from that calculated using the dielectric constant was judged insignificant. However, this error increases for larger values of characteristic impedance and may prove to be quite significant for other laminates or narrower line widths. A good precaution would be to measure wavelength versus line width on each laminate used before TEM propagation is assumed.

Although the lines can be produced by a masking-etch process, adequate results can be obtained by cutting the desired strip from a thin copper sheet and glueing this strip to the teflon glass board. The latter is a convenient method for making rapid design changes.

The author observes several precautions which may or may not be necessary for all applications:

1. All breadboards have a ground strap which encompasses the outer periphery of the board. This strip is soldered to both the top and bottom copper sheets to effectively ground the outer periphery of the amplifier on all four sides. The circuit dimensions are held to a minimum to keep the ground planes as short as possible.

2. All RF connectors are carefully connected with grounding surfaces soldered to the ground plate. For instance, mount the connectors* perpendicularly to the board at a point where the connection to the center conductor is a minimum length. Completely solder the outer conductor to the copper sheet on the opposite side of the board. Poorly mounted connectors may result in poor transitions and unpredictable impedance transformations. For example, tacking the outer barrel of this connector to the line side of the board may seriously alter the predicted impedance level at the collector.

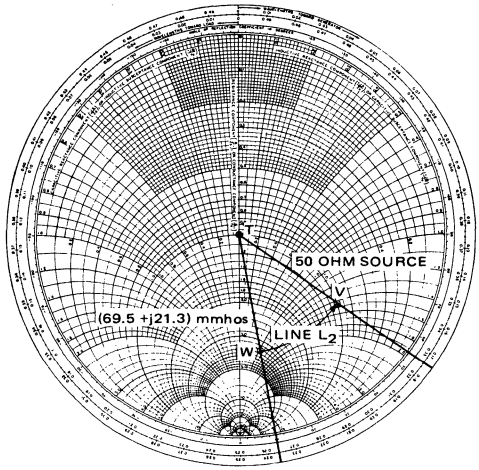


**FIGURE 6 – INPUT NETWORK DESIGN**

The amplifier was constructed as specified and the admittance levels were measured at the emitter and collector pins. These admittance levels were checked and adjusted to the original design values with $C_1$, $C_2$, $C_3$, and $C_4$

The 2N4957 was then soldered directly into the circuit with minimum lead length. The resultant power gain was 14.3 dB and the noise figure, 6.5 dB, which is within 1 dB of the original design requirements. Attempts to re-adjust the input loading and output loading for lower noise figure resulted in lower noise figure with decreased circuit stability. Although the circuit (adjusted for minimum noise figure) didn't oscillate, the calculated k factor from the resultant input and output admittances was approximately 2.

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*General Radio Cable Connector 874-G58B.

## LOW NOISE DESIGN

Improvement in noise figure is possible by arbitrarily adjusting the input and output loading. For the purpose of this paper, the stability factor (k = 4) will be retained.

However, the design curves represent the maximum power gain case. Although the circuit stability factor can be maintained at k = 4, varying the source loading will result in less power gain than indicated in the design curves.

The procedure for this case is as follows:

First, the optimum source resistance is calculated (see Appendix ) and found to be 43Ω.* The calculated noise figure for this source is 5 dB. In addition, the source reactance was empirically determined to be inductive (j119Ω).

Second, the collector loading was calculated for a stability factor of 4. Using these values of source resistance and stability factor, the calculated gain ($G_T$) and collector loading is 11.8 dB and 3.41 mmhos −7.5 mmhos (neglecting stray capacitance).

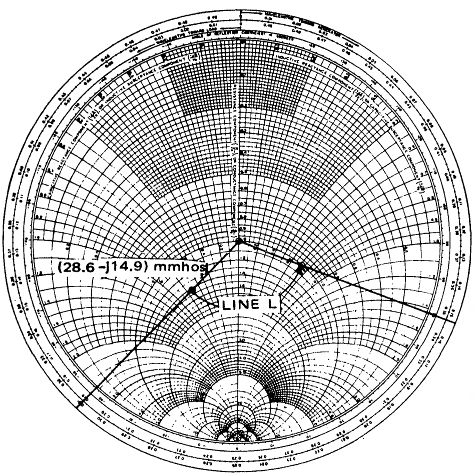



FIGURE 7 – LOW NOISE INPUT DESIGN

The output network was readily adjusted to the desired collector loading. However, the input line was too short and required re-design (see Figure 7). The calculated value of this line length is 1.15 inches as contrasted with .46 inches used in the first example. The complete amplifier is shown in Figure 9.

The resultant power gain and noise figure was 11.8 dB and 5.5 dB. These figures compare well with the calculated design.

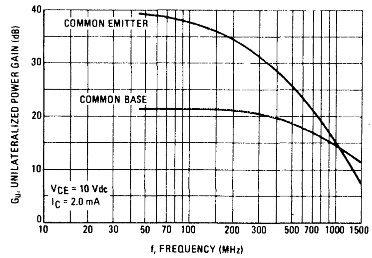



FIGURE 8 – UNILATERALIZED POWER GAIN versus FREQUENCY

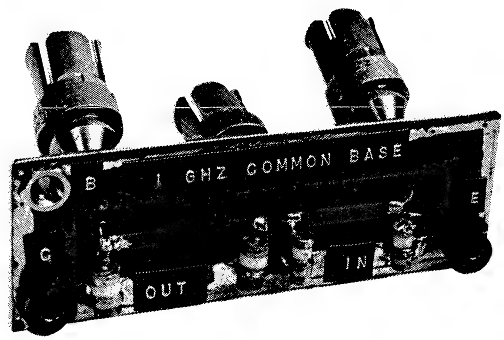



FIGURE 9 – 1 GHz AMPLIFIER

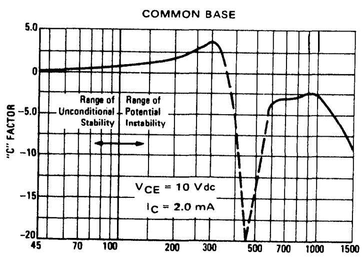



FIGURE 10 – LINVILL STABILITY FACTOR versus FREQUENCY

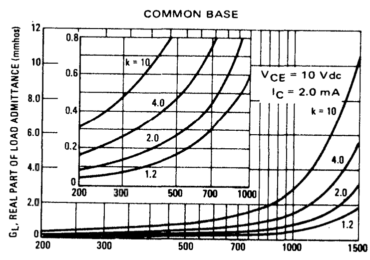



FIGURE 11 AND 12 – LOAD ADMITTANCE versus FREQUENCY (REAL)

*The actual value of optimum source resistance was empirically determined to be 35Ω. Consequently this value was used for the input circuit design rather than 43Ω.

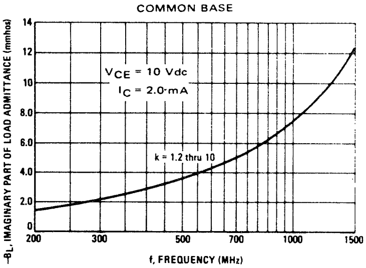



**FIGURE 13 – LOAD ADMITTANCE versus FREQUENCY (IMAGINARY)**

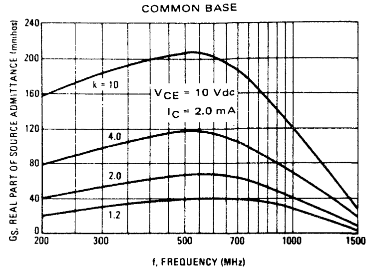



**FIGURE 14 – SOURCE ADMITTANCE versus FREQUENCY (REAL)**

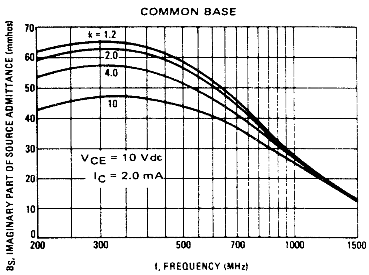



**FIGURE 15 – SOURCE ADMITTANCE versus FREQUENCY (IMAGINARY)**

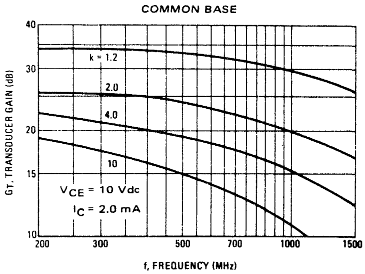



**FIGURE 16 – TRANSDUCER GAIN versus FREQUENCY**

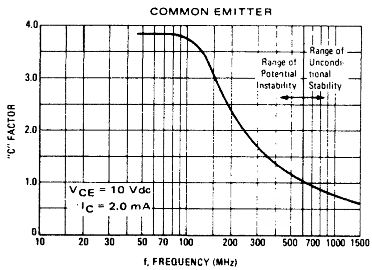



**FIGURE 17 – LINVILL STABILITY FACTOR versus FREQUENCY**

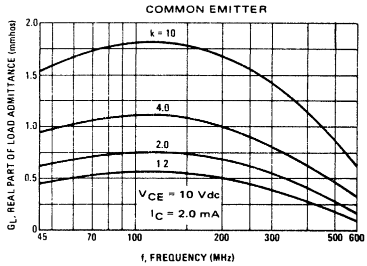



**FIGURE 18 – LOAD ADMITTANCE versus FREQUENCY (REAL)**

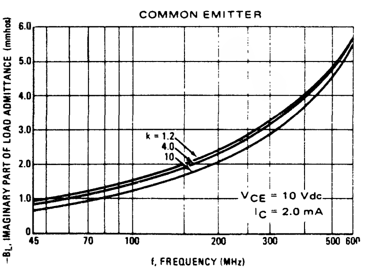



**FIGURE 19 – LOAD ADMITTANCE versus FREQUENCY (IMAGINARY)**

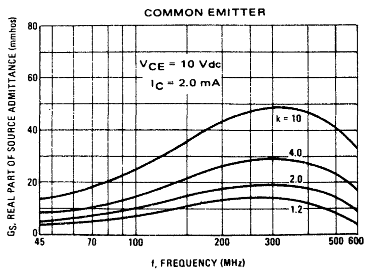



**FIGURE 20 – SOURCE ADMITTANCE versus FREQUENCY (REAL**

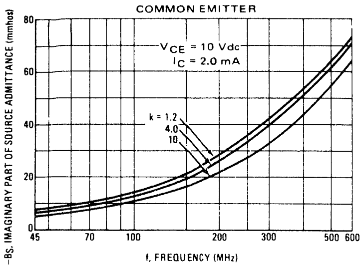



**FIGURE 21 – SOURCE ADMITTANCE versus FREQUENCY (IMAGINARY)**

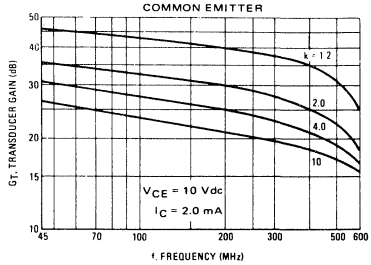



**FIGURE 22 – TRANSDUCER GAIN versus FREQUENCY**

## APPENDIX

### LOW NOISE DESIGN

The procedure followed in designing this amplifier is to first calculate the optimum source resistance for optimum noise figure and then calculate the collector loading for a required value of k.

A first approximation of optimum source resistance for optimum noise figure is:[2]

$$R_{gF(opt)} = \sqrt{k_2^2 + \frac{k_1}{k_3}}$$

$$k_1 = r_b + \frac{r_e}{2}$$

$$k_2 = r_b + r_e$$

$$k_3 = \frac{1 + (B_o + 1)\left(\frac{f}{f_{ab}}\right)^2}{2B_o r_e}$$

Assuming the above parameters for the 2N4957 are:

$r_b$ = 12.5 ohms
$r_e$ = 13 ohms
$B_o$ = 40
$f_{ab}$ = 1600 MHz,
$\therefore R_{gF(opt)}$ = 43 ohms

The noise figure using this source resistance is available from Nielsen's equation:[2]

$$NF = 1 + \frac{r_e}{2R_g} + \frac{r_b}{R_g} + \frac{(R_g + r_e + r_b)^2}{2 B_o R_g r_e}\left[1 + (B_o + 1)\left(\frac{f}{f_{ab}}\right)^2\right]$$

Using the previous parameter values,

$$NF = 5 \text{ dB}$$

Since the impedance level is different at the base, the collector loading must be re-designed.

Using Stern's stability equator for k = 4 (see Table 1):

$$k = \frac{2\left(g_{11} + G_s\right)\left(g_{22} + G_L\right)}{\left|y_{12}y_{21}\right| + \mathrm{Re}\left(y_{12}y_{21}\right)}$$

and calculating $G_L$ for $G_S$ = 25 mmhos (40 ohms)

$$G_L = 3.41 \text{ mmhos}$$

The transducer gain can be calculated from these impedance levels:

$$G_T = \frac{4\,\mathrm{Re}\left(Y_s\right)\mathrm{Re}\left(Y_L\right)\left|y_{21}\right|^2}{\left|\left(y_{11} + Y_s\right)\left(y_{22} + Y_L\right) - y_{12}y_{21}\right|^2}$$

$$G_T = 11.8 \text{ dB}$$

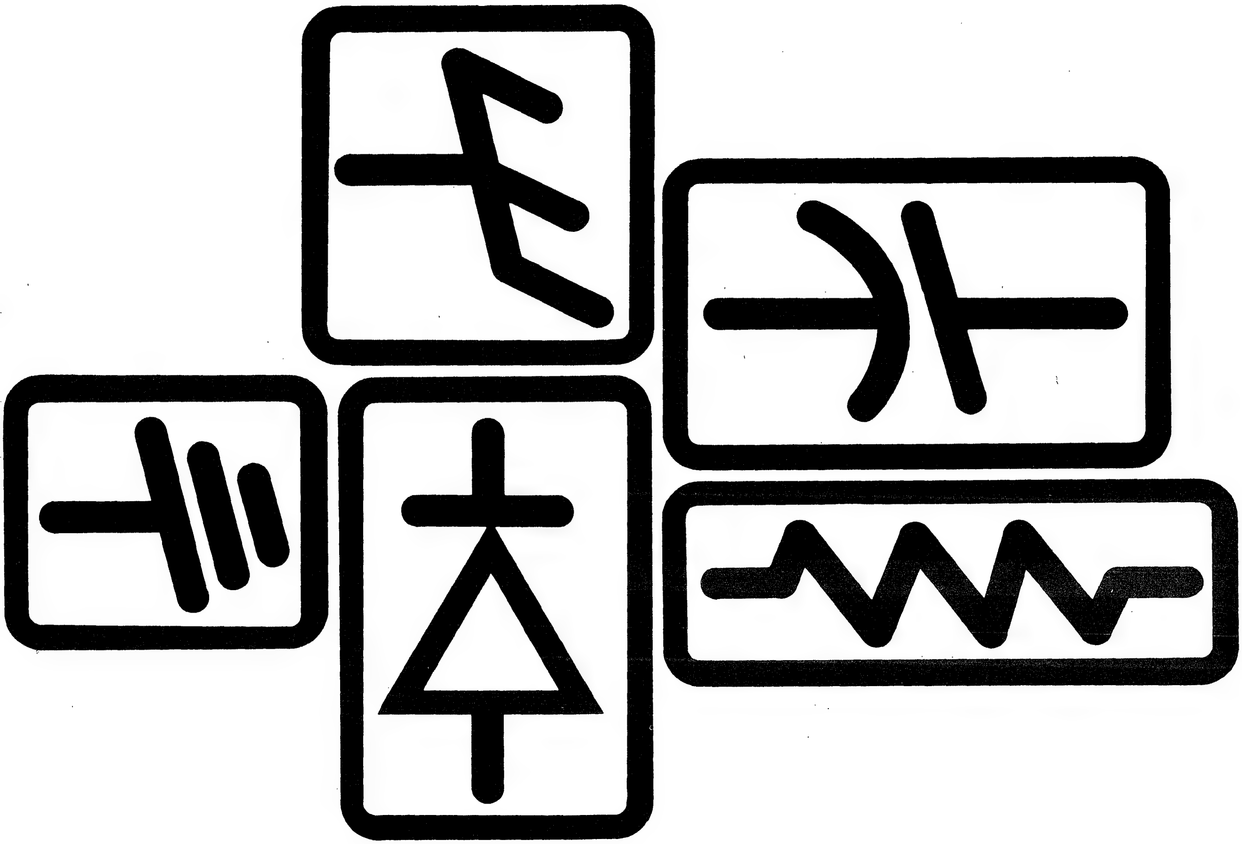
| TABLE 1 |
|---|
| f = 1 GHz $V_{CB}$ = 10 V $I_C$ = 2 mA |
| $y_{ib}$ = 25 –j25 |
| $y_{ob}$ = 0.55 +j7.54 |
| $y_{fb}$ = –4.99 +j41 |
| $y_{rb}$ = –0.01 –j1.19 |

### REFERENCES


1. R. Hejhall, "RF Small Signal Design Using Admittance Parameters", Motorola Application Note AN-215A, Motorola Semiconductor Products, Inc., Phoenix, Arizona.
2. E. G. Nielsen, "Behavior of Noise Figure in Junction Transistors," Proc. IRE, Vol. 45, p. 957, July 1957.
3. F. Assadourian and E. Rimai, "Simplified Theory of Microstrip Transmission Systems", Proc. IRE, pp. 1651-1663, December 1953.
4. M. Arditi, "Experimental Determination of the Properties of Microstrip Components," Electrical Communication, December 1953.

# GENERAL TECHNICAL INFORMATION

# CHAPTER 17



# Controlled-Q RF Technology-
# What It Means, How It's Done

*The difficult transfer of high frequency energy from a signal source to the control element of an RF power transistor is efficiently achieved by a new design philosophy. Both monolithic and hybrid IC techniques are used to include a matching network in the transistor package and overcome this tough design problem.*

The insertion of a matching network into an RF power transistor package has cured many evils encountered in high frequency circuit design. Devices using such an internal impedance matching network have been dubbed Controlled Q because that is exactly what the added package circuitry does — it gives the power transistor a consistent and highly controlled electrical quality (Q) factor. In a nutshell controlled Q increases guaranteed gains from previously available 4 dB to 5 or 6 dB in the 470 MHz region at 12.5 V. The controlled Q means that these devices are easier to match into circuit networks, and offer better consistency of high frequency parameters than other, non-controlled Q RF power devices.

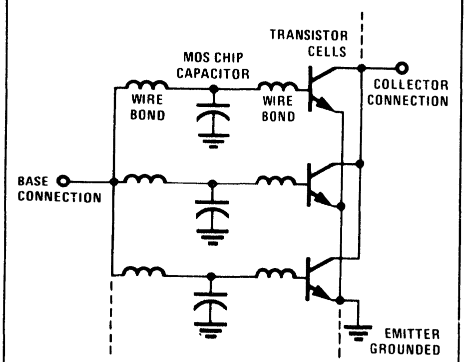



**FIGURE 1** — Each base region has an internal matching network included in the CQ package.

### The Old and the New

There are no panaceas for the complexities of broadband RF circuit design. With or without controlled Q, circuit networks must be designed to impedance-match the different stages. Gain and power output has to be optimized for the particular application, while maintaining a specified overall circuit bandwidth.

With older RF power devices, such as the 2N6136, a complete interstage matching network had to be provided using discrete passive components external to the transistor package. Not only did the circuit take up a lot of space, but its overall series component reactance limited design capability — especially in bandwidth. In addition, parasitic elements caused by the extra components, and package geometries interfered with establishing a solid signal ground.

With newer controlled Q devices, "inside-the-package" construction of some of the network matching elements brings the network closer to the active transistor die. Not only does this eliminate the number of required external components, but it also means that a small amount of capacitance can minimize the imaginary part of the input impedance for maximum bandwidth. Internal construction techniques help establish a better signal ground by removing most parasitic reactance.

### A Closer Look

Controlled Q transistors use both monolithic and hybrid techniques in their construction. The active transistor die is fabricated using monolithic integrated circuit methods. A small MOS chip capacitor is wire bonded to the active transistor die thus incorporating hybrid technology. The

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resulting total transistor package can be thought of as an active transmission line element for high frequency (to 500 MHz) amplifier design. Figure 1 shows a portion of the device circuit.

To meet the high power handling requirements the controlled Q transistors are specially constructed with each of its multiple emitters having its own ballast resistor. These nichrome (NiCr) resistors, shown in the close-up of Figure 2, have different resistance values to compensate for thermal differences of various portions of the transistor chip. This prevents overloading of some emitters due to temperature difference. This Isothermal* resistor design technique assures balanced current distribution throughout the transistor for more consistent operation at various power levels.

Emitter inductance and its undesirable gain reducing negative feedback are minimized in controlled Q devices, by establishing a solid ground for the transistor emitters. This is accomplished by using the lead frame to extend the ground plane completely around the device. Emitter wires are then attached to this ground plane. Such an emitter bonding technique has been shown to contribute more than 50% of the gain increase of a controlled Q device in the 470 MHz region. Its total gain of 5.22 dB is significantly higher than a non-CQ device of the same 25 W version that gives around 4.0 dB gain.

Controlled Q transistors also have bonding wires extending from each transistor base region to the MOS capacitor chip and then out to the package base lead. These bonding wires and the MOS capacitor interconnect one half of an input impedance matching network as in Figure 3.

*Trademark of Motorola Inc.*

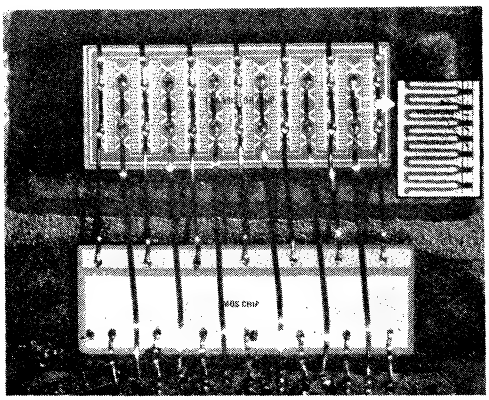

**FIGURE 2**— A close-up view of the emitter ballasting resistors.

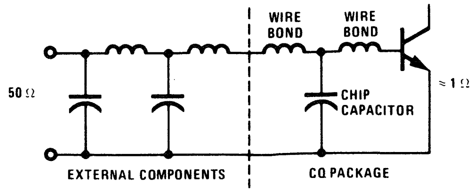


**FIGURE 3** – Part of the transmission network inductance and capacitance is provided in CQ transistor packages.

Controlled Q production methods not only increase device yield, but also allow all final factory testing to be done in fixed-tuned test equipment. This means ease of final test for the semiconductor manufacturer, but more importantly, insures the consistency of controlled Q transistors from device to device. To the RF equipment manufacturer, this means that once a piece of communications gear has been designed, controlled Q devices can be dropped into amplifier modules with a minimum of circuit adjustment and tuning.

### What's Available

Motorola's MRF series of high frequency power devices are available in stripline opposed emitter packages which offer excellent thermal characteristics along with controlled Q operation. Available in both 12.5 V and 28 V devices, these transistors listed in Table I are capable of operating at frequencies to 900 MHz with power outputs to 50 watts.

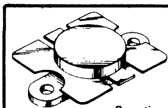

TABLE I – Controlled Q RF Power Transistors

| Device | Operation Voltage | Output Power | Frequency | Comment |
|---|---|---|---|---|
| MFR243<br>MRF245 | 12.5 V | 60 W<br>80 W | to 175 MHz | For VHF Large Signal Application |
| MRF 316<br>MRF317 | 28 V | 80 W<br>100 W | to 200 MHz | For VHF MIL Aircraft and Mobile Operation |
| MRF641<br>MRF644<br>MRF646<br>MRF648 | 12.5 V | 15 W<br>25 W<br>40 W<br>60 W | to 512 MHz | For UHF FM Mobile Applications |
| MRF321<br>MRF323<br>MRF325<br>MRF326<br>2N6439<br>MRF327 | 28 V | 10 W<br>20 W<br>30 W<br>40 W<br>60 W<br>80 W | to 500 MHz | For 225-400 MHz Aircraft and Mobile Operation |
| MRF840<br>MRF842<br>MRF844*<br>MRF846* | | 7 W<br>20 W<br>30 W<br>40 W | to 900 MHz | For 900 MHz Land Mobile |

*To Be Introduced

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# A Metallization System for UHF and Microwave Power Transistors

ALUMINUM METALLIZATION

The limitations of aluminum metallization were noted in some early integrated circuits where narrow interconnect patterns and high device densities pushed the current densities to an intolerable level. Subsequent studies by J.R. Black (Motorola SRDL) and others defined exactly what the limitations of aluminum are and what might be expected of some other materials as well.

The failure rate over temperature for aluminum at a current density of $3 \times 10^5$ A/cm$^2$ is shown in Figure 1.

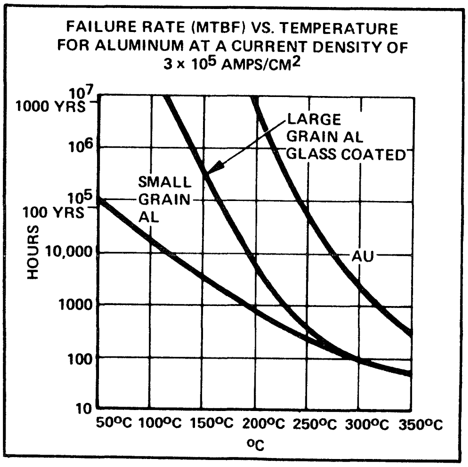


FIGURE 1

In some early designs it was not uncommon to encounter this density level, and as can be seen from the graph, for fine-grain aluminum, at 200°C the mean time before failure (MTBF) is less than 900 hours! To some, the 200°C level might seem somewhat extreme but conservative design is an absolute necessity for high reliability in the high-frequency power area. Figure 2 gives the MTBF vs. current at 200°C for a conductor stripe 12.7$\mu$ wide by 1$\mu$ thick. Given the desired operating current level it is quite simple to calculate the MTBF.

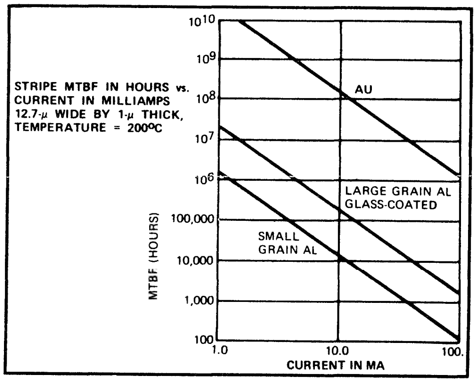


FIGURE 2

It should be noted here that the source of these curves and of most of the MTBF numbers quoted here and elsewhere in the industry are from tests on carefully controlled test vehicles consisting of dog-bone resistor patterns, or, in some cases, from theoretical calculations based on the activation energy of the material involved.

The familiar metal migration or electromigration of the conductor also has some secondary effects. At the point where silicon and aluminum are in contact, silicon is removed and replaced by aluminum. The SEM photo, Figure 3, shows the "etch-pit" formation that results.

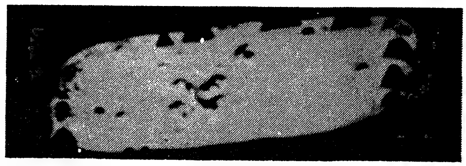

FIGURE 3

This phenomenon seems to occur much more rapidly along the silicon/silicon dioxide interfaces. In RF power devices this can ultimately lead to emitter-base shorts if the device is operated at elevated power and/or temperature for extended periods. The use of a "barrier" metal or layer between the aluminum and silicon has proved to be a workable solution.

**STEP COVERAGE OF 1.2 MICRONS OF Al OVER 0.75 MICRON TAPERED OXIDE STEP**

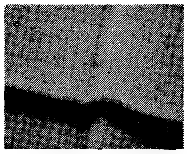

FIGURE 4

Another potential reliability problem that is more related to deposition methods than to the materials is step coverage of aluminum films over the $SiO_2$. Figure 4 shows the ideal case but in fact the extremes range from the ideally tapered (A), to the sharply under-cut (B) shown in Figure 5.

SCHEMATIC DIAGRAM OF TWO TYPES OF STEPS THAT OCCUR IN DEVICE FABRICATION

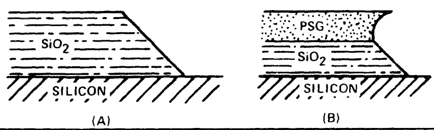


FIGURE 5

With the sharply under-cut condition a microcrack in the metallization can form. This microcrack is represented in Figure 6. The microcrack is nearly impossible to detect with a normal microscope.

SCHEMATIC CROSS SECTION SHOWING MICROCRACK IN DEPOSITED METAL FILM

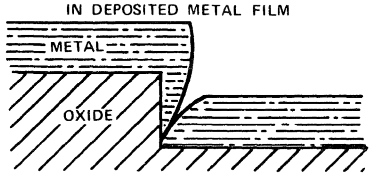


FIGURE 6

## OTHER METALLIZATION SYSTEMS

A replacement for the aluminum contact system we have used successfully for a long time, a system which is outmoded *only* on "state-of-the-art" semiconductor devices, must be approached with great care. The change of contact metals may well approach in significance and difficulty the switch from silicon mesa to the silicon planar technology. It is important that the change be carried out in a disciplined and ordered fashion. Dick Wilson, Lou Terry, and others at Motorola have considered a variety of metal systems and tested them for performance. Considerations for any new metallization system are shown in Table I.

| | |
|---|---|
| A. | The material should have a high conductivity ($\rho < 10\mu$ ohm-cm). |
| B. | It should have good adhesion to both the semiconductor material and to thermally grown or deposited dielectric films. |
| C. | The metal or metals should be free from degrading intermetallic compounds not only between metal films but between the metal and the semiconductor. |
| D. | Should make a good low ohmic contact to both P- and N-type silicon. |
| E. | Amenable to practical production methods of deposition and delineation. |
| F. | Resistant to current induced electromigration. |
| G. | Resistant to electrochemical corrosion. |
| H. | The deposition of the metal or metals must not introduce surface instabilities in the semiconductor material. |
| I. | The metallization system must be compatible with LSI arrays involving multilayer interconnection processing. |

TABLE I

Only the first four or five materials in Table II can be seriously considered for UHF and microwave power devices due to the necessity of keeping resistive losses as low as possible for a given pattern configuration. Silver can be eliminated due to the tendency to oxidize in normal environments. Copper can be eliminated for similar reasons. We don't know much about beryllium from a processability standpoint, except for the toxicity of its oxides. At any rate, this material is a little high in resistivity. Discounting Al, since it is the one we wish to replace, we are left with gold.

| Metal | Volume Resistivity in Micro-ohm Centimeters | Ohms Per/Square for 6000 A – Thick Film | Resistance of A 10-Mil-Long Conductor 2-Microns Wide X 6000 A Thick |
|---|---|---|---|
| Ag | 1.61 | 2.7 X $10^{-2}$ | 3.4 (ohms) |
| Al | 2.74 | 4.6 X $10^{-2}$ | 5.8 (ohms) |
| Au | 2.44 | 4.1 | 5.2 |
| Cu | 1.70 | 2.8 | 3.5 |
| Be | 3.25 | 5.42 | 6.9 |
| Ir | 5.3 | 8.3 | 11.1 |
| Mg | 4.3 | 7.2 | 9.1 |
| Mo | 5.3 | 8.8 | 11.1 |
| Ni | 7.8 | 13.0 | 16.5 |
| Pd | 10.8 | 18.0 | 22.5 |
| Pt | 9.8 | 16.4 | 10.5 |
| Rh | 4.7 | 7.8 | 9.9 |
| W | 5.3 | 8.8 | 11.2 |

TABLE II

| ELECTROCHEMICAL CORROSION TEST RESULTS | | | |
|---|---|---|---|
| METAL | TYPE OF FAILURE | TIME | REMARKS |
| Al | All contacts open | 5 min | (-) terminal somewhat faster |
| Ti-Pt-Au | Resistance increase | · 3 hrs | Au deplates (+) |
| Ti-Pt | Slight resistance change | ·24 hrs | Au wire bond opened |
| Ti-Rh | Slight resistance change | ·24 hrs | Au wire bond opened |
| Cr-Ag-Au | Open (Cr) | · 5 min | Cr from under Ag-Au, even with glass or $Si_3N_4$ overcoat |
| Ti-Ag | Large Resistance increase | · 5 min | Ag corrodes but not removed |
| Hf-Au | Resistance increase | · 3 hrs | Au deplates (+) |
| Ti-Ag-Au | Resistance Increase | · 3 hrs | Au deplating (+) |
| Ti-Mo-Au | Open (Mo) | · 5 min | Mo from between Ti & Au |
| Ti-Au | Resistance increase | · 3 hrs | Au deplates (+) |
| Mo-Au | Open (Mo) | · 5 min | Mo from under Au, even with glass overcoat |
| Cr-Au | Open ((Cr) | 5 min | Cr from under Au |
| W-Au | Resistance Increase | 2-3hrs | W removed same rate as Au |
| Zr-Au | Resistance increase | · 3 hrs | Au deplates (+) |
| Nb-Au | Resistance Increase | · 3 hrs | Au deplates (+) |
| Ta-Au | Resistance Increase | · 3 hrs | Au deplates (+) |
| Ni-Au | Resistance Increase | · 3 hrs | Au deplates (+) |
| Co-Au | Pesistance Increase | · 3 hrs | Au deplates (+) |
| V-Au | Open (V) | · 5 min | V removed (+) from under Au |

TABLE III

The test which was used to generate the data shown in Table III was performed in a 95°C, 95% relative humidity environment. The test structure consisted of two parallel dogbones on $SiO_2$ coated silicon, the first biased positively relative to the second. The results are of course relative. We will note three of the materials listed. Aluminum performed unacceptably on this test. Both Ti-Pt-Au (the Bell Process) and W-Au performed satisfactorily. The only difficulty with the Bell Process is the inability to define the very tight lines and spaces of some microwave and UHF transistor designs.

| Metal Silicon Contact Resistance in Ohms, Area $10^{-4}$ $cm^{-2}$ | | | | | | |
|---|---|---|---|---|---|---|
| Resistivity (ohm-cm) and Type | Metals | | | | | Metal + PtSi |
| | Al | Mo | Ni | Cr | Ti | |
| 0.001 N | 0.09 | 0.08 | 0.02 | 0.03 | 0.01 | 0.02 |
| 0.01 N | 6 (R) | 5 (R) | 2 | 3 (R) | 4 | 0.2 |
| 0.1 N | | | | | | 45 (R) |
| 0.002 P | 0.03 | 0.06 | 0.02 | 0.04 | 0.01 | 0.02 |
| 0.04 P | 1 | 3 (R) | 4 (R) | 8 (R) | | 1.0 |
| 0.08 P | | | 45 (R) | | | 3 |
| 0.5 P | 20 | 80 (R) | 100 (R) | 200 (R) | | 15 |

(R) Indicates rectifying contact identified by the relation

TABLE IV

Contact resistances of various material to the range of resistivities of both N- and P-type silicon are shown in Table IV. Note that gold is missing–it alloys with silicon at unacceptably low temperatures and cannot be considered as the contact material. The significant fact is that Pt-Si in conjunction with any metal is as good as or better than any material on the chart, with the exception of two points on Ti. Pt-Si has an additional advantage in that the formation of the silicide can be checked visually prior to proceeding with further processing.

Looking again at the MTBF due to electromigration induced failures as shown in Figure 1, it should be noted that with gold no significant problem exists until much higher current densities than those now imposed are encountered.

At 3 X $10^5$ A/cm$^2$, and 200°C the MTBF due to electromigration of gold is 1000 years, while under the same conditions–using fine-grain aluminum the MTBF is ≈ 800 hours.

Wilson and Terry using the knowledge of materials gained in these and other tests, developed a structure consisting of platinum silicide used to make contact to the silicon, titanium for adhesion to $SiO_2$ and Si, tungsten to act as a barrier against gold alloying with the silicon, and gold to act as the main conductor material. The gold pattern was to be defined by sputter-etching using molybdenum as a sacrifical mask.

After careful consideration, RF-diode sputtering rather than DC was chosen as the deposition technique to be used in a production process. See Table V.

| ADVANTAGES | DISADVANTAGES |
|---|---|
| 1. Simple Two Element Construction<br>2. Available From Many Manufacturers<br>3. Easy To Introduce Substrate Bias And Heating<br>4. Optimum Conditions For Good Step Coverage – (Source-High Gas Pressure)<br>5. RF Systems Deposit From Insulating As Well As Conducting Target Materials | 1. High Voltage And Consequently Energic Particles, Produces Substrate Damage<br>2. Large Targets Needed For Large Capacity<br>3. Difficulty In Bonding Large Targets<br>4. Considerable Substrate Heating From Bombardment<br>5. Film Properties May Be Affected By Gas Occlusion |

TABLE V

Figure 7 shows the Ti, W, Au structure covering what can only be described as a worst case step condition. If there is a micro-crack there, it is not apparent in this view.

SEM MICROGRAPH OF STEP COVERAGE OF Ti-W-Au SPUTTERED FILM OVER UNDERCUT POLYSILICON STEP

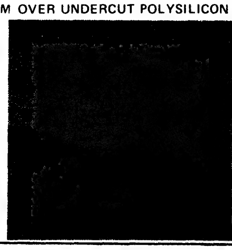

FIGURE 7

The procurement of a production-worthy sputtering system for implementation of this metallization required a large amount of study.

The Pt-Si machine incorporates a heated anode for in situ formation of the silicide. The system is automatically

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tuned, has auto pressure control, and has provisions for sputter etch and bias sputter. The pallets are loaded in the machine by use of the "intervac" pallet injection system.

The 4-target turret head machine is used to deposit Ti, W, Au, Mo in sequence. This system uses a water-cooled anode, auto tune, auto pressure, and the intervac pallet injection system. The machine also has provisions for sputter etch and bias sputter.

The sputter etch machine is used to define the gold contact pattern. Auto tuning is incorporated along with automatic vacuum system control.

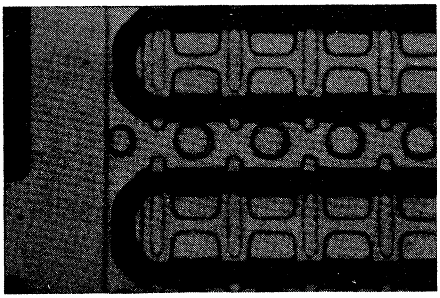


FIGURE 8

Results achieved with this system are shown in Figures 8 and 9, representing a low-voltage, 35-W, 470-MHz power transistor normally utilized in land-based mobile communications applications.

The process demonstrated is now ready for full production utilization. Life testing on devices fabricated in this system have produced zero failures (1,000,000 current cycles/device).

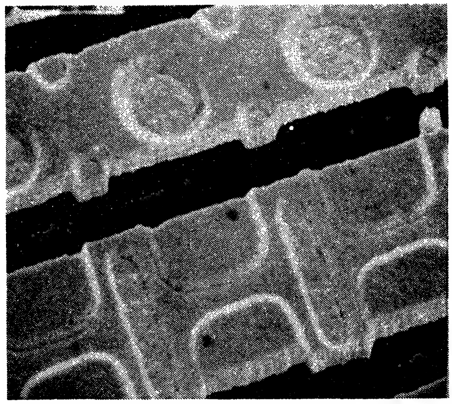


FIGURE 9

**BIBLIOGRAPHY**:


Proceedings of 1967 Annual Symposium, Reliability Physics, IEEE, Cat. No. 7-15C50, Nov. 1967.

IEEE Proceedings, Sept. 1969, "Metallization Systems for ICs."

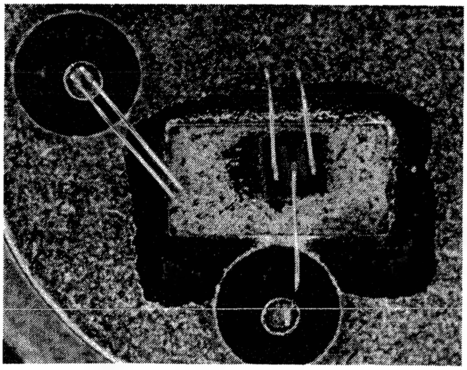
IEEE Proceedings, Jan./Feb. 1970, "metallization Systems for ICs."

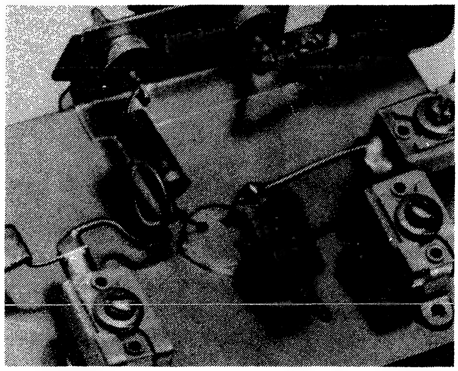
INTER/NEPCON Proceedings, Oct. 1970, "Metallization Systems for ICs."

INTER/NEPCON Proceedings, Feb./June 1970, "Metallization Systems for Semiconductor Devices."

WESCON 1971 Technical Papers, Aug. 1971, "Metallization Systems for Semiconductor Devices."

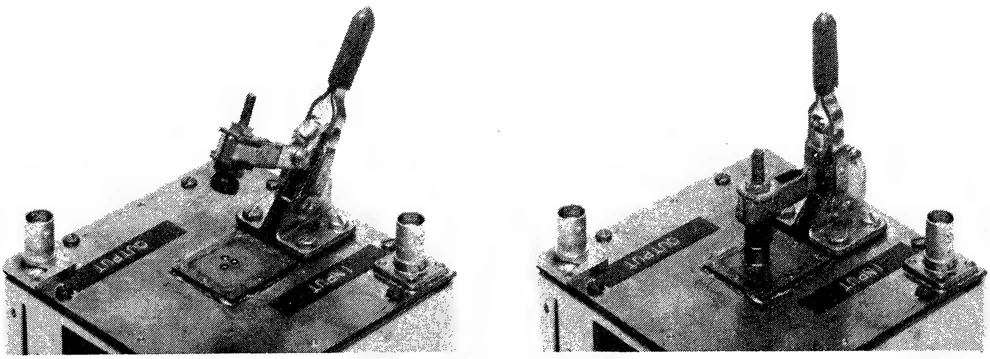
# The Common Emitter TO-39 And Its Advantages





The common emitter TO-39 package is one of Motorola's latest innovations in low-cost rf packages. It differs from conventional TO-39's or TO-5's in that the emitter, not the collector, is connected to the metal case. To achieve this, a BeO insulating block metallized on top and bottom is brazed to the can bottom and the transistor chip brazed to the BeO insulator. Wires are then bonded from the chip and insulator block to the terminals and the can bottom as shown in the photo. With NPN transistors, this configuration permits direct connection of the can to rf and negative dc ground for many class B and C circuits.

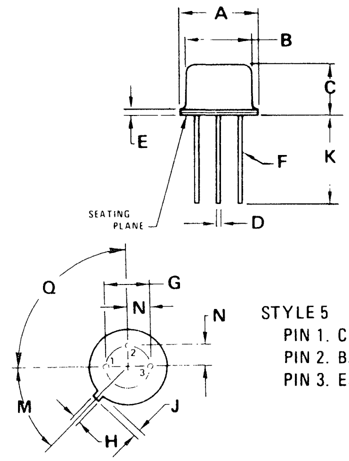
Two important advantages can be derived from the common emitter TO-39: By connecting the case to the rf circuit ground, emitter inductance is reduced and gain increased by 3 to 5 dB over that of comparable, conventionally wired transistors. And the case may be directly pressed, clipped, or soldered to the heat sink with no effect on rf performance. This feature may eliminate the need for the heat radiating "coolers" because soldering the transistor bottom to the circuit, typically a PC board, improves dissipation by removing heat through the thick metal base rather than the thin can.



Fixture for Functional Testing of the Common Emitter TO-39

| DIM | MILLIMETERS MIN | MILLIMETERS MAX | INCHES MIN | INCHES MAX |
|---|---|---|---|---|
| A | 9.02 | 9.30 | 0.355 | 0.366 |
| B | 8.00 | 8.51 | 0.315 | 0.335 |
| C | 4.19 | 4.57 | 0.165 | 0.180 |
| D | 0.43 | 0.53 | 0.017 | 0.021 |
| E | 0.43 | 0.89 | 0.017 | 0.035 |
| F | 0.41 | 0.48 | 0.016 | 0.019 |
| G | 4.83 | 5.33 | 0.190 | 0.210 |
| H | 0.71 | 0.86 | 0.028 | 0.034 |
| J | 0.74 | 1.02 | 0.029 | 0.040 |
| K | 12.70 | – | 0.500 | – |
| M | 45° NOM | | 45° NOM | |
| N | 2.54 TYP | | 0.100 TYP | |
| Q | 90° NOM | | 90° NOM | |

All JEDEC dimensions and notes apply.




STYLE 5
PIN 1. COLLECTOR
PIN 2. BASE
PIN 3. EMITTER

**CASE 79-03**
**TO-39**

**ISSUE "H" (4-24-74)**

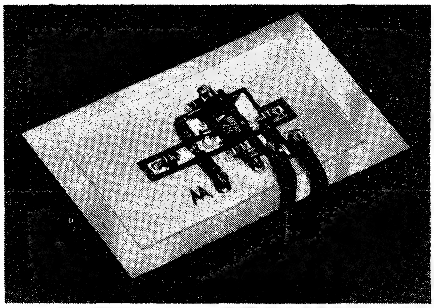
For example, the MRF227 was mounted in this manner and a $\theta_{jc}$ of 15°C/W was measured using a Barnes RM-2A Infrared Microscope. Compared to an MRF607 in a conventional package operating under identical conditions, this is greater than a 2:1 reduction in thermal resistance. And as side benefits, the lower $\theta_{jc}$ also reduces power slump and improves reliability.

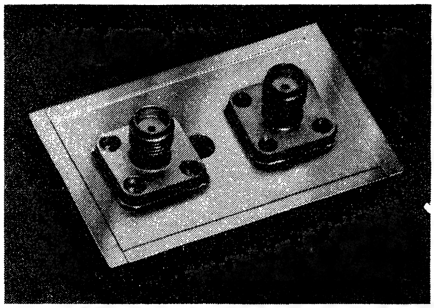
In many mobile radios CE-TO39 devices can replace stud or flange mounted stripline parts used for 1- to 4-watt drivers. This conversion should normally offer a significant savings in the cost of parts as well as the costs of mounting hardware and labor.

The designer of compact handheld radio equipment will find the CE-TO39 offers a real advantage from the elimination of interstage RFI or coupling because the can is at rf ground. Stability is usually improved and the higher available gain may reduce the number of transmitter stages. Simplified and improved cooling may also be obtained by connecting the can directly to the radio housing or chassis.

To sum it up: The emitter-to-can wired TO-39 known as the CE-TO39 offers the designer significant improvements in both gain and thermal performance. Because of its price, compared to SOE and TO-60 packages, the designer can use the CE-TO39 to reduce costs. And he can make his design easier to assemble with no loss in rf performance.

# Amplifier Gains 10 dB Over Nine Octaves





By: Mike Hadley

The introduction of Motorola encapsulated transistors fabricated with ion-implanted arsenic emitters has made a reality of economical small-signal amplifiers with bandwidths exceeding 1 GHz. The recently developed MRF901, an example of this technology, has an $f_T$ exceeding 4.5 GHz, and a maximum noise figure at 1 GHz of 2.5 dB. The device package (case 302) employs the Motorola dual emitter bonding concept to minimize parasitic inductance and enhance high-frequency performance.

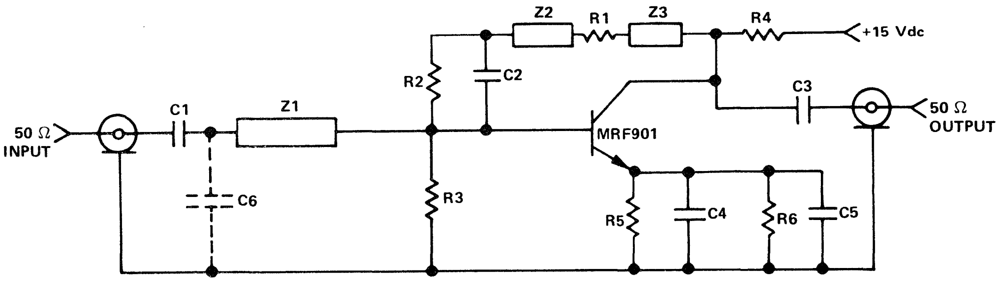
Using the MRF901, an amplifier has been developed which exhibits a nominal gain of 10 dB over nine octaves of bandwidth. The circuit design is a class A amplifier employing both ac and dc feedback. Bias is stabilized at 15 mA of collector current using dc feedback from the collector. The ac feedback from collector to base, and in each of the partially bypassed emitter circuits, compensates for the increase in device gain with decreasing frequency, yielding a flat response over a maximum bandwidth. Transistor S parameters, as provided by the MRF901 data sheet, and computer-aided circuit optimization techniques were used to choose component values for gain flatness, input VSWR and output VSWR. The described performance was achieved using common high-frequency amplifier construction techniques and a standard printed circuit board substrate. Even better results could be expected from the use of today's hybrid circuit technology.

Evaluation of the amplifier shows a nominal 10 dB power gain from 3 MHz to 1.4 GHz. With only a minimum matching network used at the amplifier input, the input VSWR remains less than 2.5:1 to approximately 1 GHz while the output VSWR stays under 2:1 to approximately 1.4 GHz (figure 2). If input impedance matching were of prime consideration, connecting a 2.1 pF capacitor from the junction of C1 and Z1 to ground (C6 in figure 1) would hold input VSWR below 2.2:1 over the complete frequency range (figure 3). Note that a slight degradation in gain flatness and output VSWR occurs with the addition of C6. A more elaborate network design would probably optimize impedance matching while maintaining gain flatness.

The amplifier was built on a glass Teflon® printed circuit board 1.8" x 1.2". A 2:1 reproduction of the circuit pattern is provided in figure 4. The type OSM215 50-ohm input and output connectors were mounted opposite the component side to facilitate laboratory measurements. Board size could be reduced to approximately half by reducing the ground plane around the circuit perimeter. A combination of chip capacitors, chip resistors and standard carbon resistors were used to obtain maximum performance at minimum cost.

Extra care was taken to keep all component lead lengths to an absolute minimum and to provide a good ground plane. In the interest of maintaining a good ground, copper foil was soldered at the board edges to connect the top and bottom circuit grounds, and an eyelet was inserted near each emitter lead.

Figure 1. Schematic Diagram




C1–C3 – 2200 pF chip capacitor
C4, C5 – 6.5 pF chip capacitor
C6 – Optional 2.1 pF chip capacitor
Z1 – 0.3" x 0.125" microstrip line
Z2 – 0.15" x 0.125" microstrip line
Z3 – 0.3" x 0.125" microstrip line
R1 – 200 Ω, 1/8" W, ±5% carbon resistor
R2 – 4.3 kΩ carbon resistor
R3 – 680 Ω carbon resistor
R4 – 560 Ω carbon resistor
R5, R6 – 15 Ω ±5% chip resistor
Substrate – 1 oz. copper, double-sided glass Teflon® board 0.0625" thick, $\epsilon_r \approx 2.5$
® Registered trademark of DuPont

Figure 2.
Gain and VSWR vs Frequency

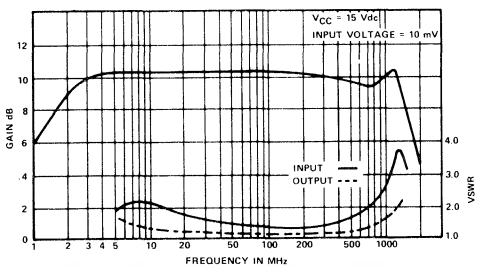



Figure 3.
Gain and VSWR vs Frequency with Matching Capacitor C6

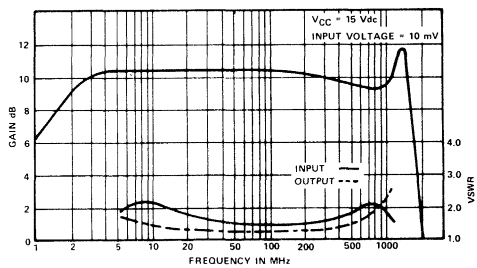



Figure 4. Amplifier PCB Artwork Scale 2:1

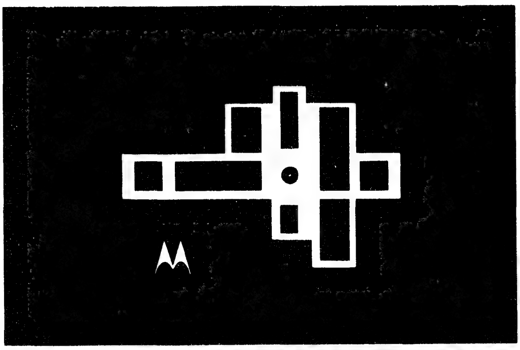
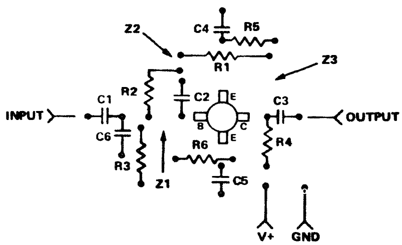


Figure 5. Parts Layout



# MOUNTING STRIPLINE-OPPOSED-EMITTER (SOE) TRANSISTORS

## INTRODUCTION

The Stripline Opposed Emitter (SOE) package presently used by Motorola for a number of rf power transistors represents a major advancement in high frequency and thermal performance. This Application Note discusses the SOE package, it advantages and limitations as well as a number of considerations to avoid improper usage.

An understanding of a few basic principles in regard to mounting and heat-sinking of this package can help avoid cases of poor performance or device damage.

Two general package types – the stud-mounted and flange-mounted SOE packages will be discussed. Each of the general types is available in a variety of sizes. Typical package outlines of the two SOE packages are shown in Figure 1.

## ADVANTAGES OF THE SOE PACKAGE

The primary electrical advantages of the SOE packages are the low inductance strip line leads which interface very well with the microstrip lines often used in UHF-VHF equipment and the good collector to base isolation provided by the two emitter leads. The two emitter concept promotes symmetry in board layout when combining devices to obtain higher output power. Both emitter leads should always be used for best performance.

## DESCRIPTION OF THE SOE PACKAGE

Figure 2 displays the component parts on a stud-mounted SOE package. This package will be used as an example since both the stud and flange-mounted packages are very similar in construction. The body of the package is a Berylium Oxide (BeO) disc. Berylium Oxide was chosen due to its high thermal conductivity. Attached to the bottom of the disc is a copper stud which is for heat transfer and mechanical mounting. The lead frame is attached to a metalized pattern on to the top surface of the BeO disc. The actual shape of the leads differs between the various package types. Finally an Alumina ceramic cap is attached to the top of the disc over the leads providing a protective cover for the transistor die.

An understanding of the basic structure of the SOE package is essential to proper usage of these devices in respect to heat-sinking and mechanical mounting. Since these two areas present the greatest problem to users, they will be discussed in detail.

## HEAT-SINKING THE SOE PACKAGE

In order to properly understand the thermal considerations involved in mounting SOE type packages, it is necessary to lay some groundwork in the area of heat flow. Table I gives equivalent Thermal and Electrical parameters which may be used to relate Thermal properties to more familiar electrical units.

Semiconductor power devices are usually guaranteed to have a certain thermal performance as stated by the thermal resistance of the device from the junction to the case, or mounting surface – $\theta_{JC}$. How to get the heat out of the

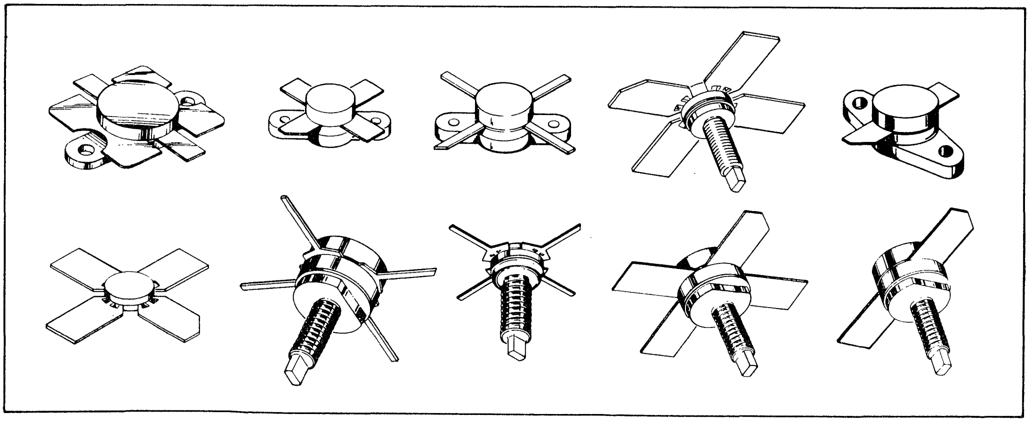


FIGURE 1 – SOE Packages

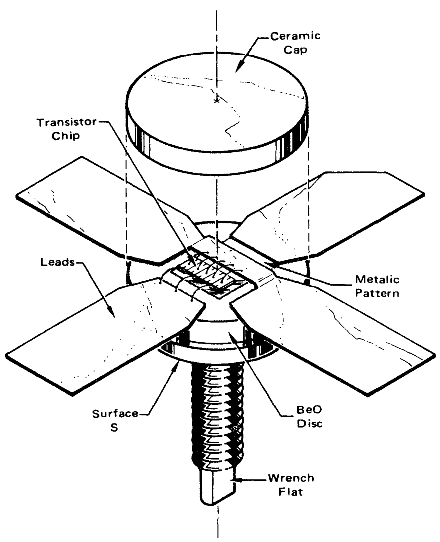



**FIGURE 2 — Component Parts of SOE Package**

case has generally been left to the user. In any dynamic heat flow problem, the heat must go somewhere, otherwise there will be a continuous rise in the temperature of the system. In text books, there always seems to be an "infinite heat sink" available which can absorb any amount of heat with no temperature rise whatsoever. In the practical sense, however, such a heat sink does not really exist. Practical heat sinks must be characterized by a certain temperature rise for a given ambient condition, with a known amount of heat input (power to be dissipated) after equilibrium conditions have been achieved. Characterization of heat-sink systems is best achieved by examining the complete system under controlled conditions.

**TABLE I — Thermal Parameters and Their Electrical Analogs**

| Symbol | Thermal Parameter | Units* | Electrical Analog Symbol | Electrical Analog Parameter |
|---|---|---|---|---|
| $\Delta T$ | Temperature difference | $^{o}C$ | V | Voltage |
| H | Heat flow | watts | I | Current |
| $\theta$ | Thermal resistance | $^{o}C$/watt | R | Resistance |
| $\gamma$ | Heat capacity | $\frac{\text{watt-sec}}{^{o}C}$ | C | Capacity |
| K | Thermal conductivity | $\frac{\text{cal}}{\text{sec-cm-}^{o}C}$ | $\sigma$ | Conductivity |
| Q | Quantity of heat | cal | q | Charge |
| t | Time | sec | t | Time |
| $\theta\gamma$ | Thermal time constant | sec | RC | Time constant |

*Note the one major difference in thermal and electrical units; Q is in units of energy, whereas q is simply a charge. Hence H is in units of power and may be equated to an electrical power dissipation.

For example, the normal environment for a land-mobile VHF transmitter might be the trunk of a taxi cab in the hot Arizona summer. In such an environment, temperatures might reach as high as 80°C (176°F). The heat-sink system for such a radio should therefore be tested at a minimum ambient temperature of 80°C. The method that should be applied in this test would utilize a fine wire thermocouple rigidly secured to the stud of the rf power transistor for which the test is being conducted. The system, which in this case would include all parts of the radio which would contribute heat, should then be operated under maximum heat generating conditions, in the high temperature environment specified. Careful measurement of the temperature of the device under test would then give the difference in temperature between the case of the transistor and the controlled ambient.

If the case and ambient temperatures are known, as well as the power levels in the transistor, the thermal resistance from the transistor case to the ambient can be calculated. The first step is to obtain the power being dissipated by the device.

$$P_d = P_1 + P_2 - P_3 \qquad (1)$$

where: $P_d$ = power being dissipated by the transistor in watts;

$P_1$ = dc power into the transistor in watts;

$P_2$ = rf power into the transistor in watts;

$P_3$ = rf power out of the transistor in watts.

This value of $P_d$ is used to obtain the $\theta_{CA}$ value from the equation:

$$\theta_{CA} = \frac{T_C - T_A}{P_d} \qquad (2)$$

where: $\theta_{CA}$ = thermal resistance device case to ambient;

$T_C$ = device case temperature;

$T_A$ = ambient temperature.

In order to determine the maximum temperature rise in the transistor element (junction temperature rise) under any given operating condition the following equation may be used.

$$T_j = (\theta_{JC} + \theta_{CA}) P_d + T_A \qquad (3)$$

where: $T_j$ = junction temperature;

$\theta_{JC}$ = published thermal resistance – junction to case.

If power is dissipated in a power transistor, the case temperature will rise above the ambient temperature by an amount determined by $\theta_{JC}$ and $\theta_{CA}$. Since the value to $\theta_{JC}$ is fixed by the transistor type being used, $\theta_{CA}$ is the only factor with which the user can control the junction temperature for a given power dissipation.

Since heat generated by the transistor must be radiated to the ambient by the heat sink, a low $\theta_{CA}$ requires an effective heat sink. In general, an efficient heat sink requires that material with high thermal conductivity and high specific heat be used. A table of thermal properties for various materials is given in the Appendix. A well-designed heat sink requires that all thermal paths be as short as possible and of maximum cross-sectional area. Examples of thermal resistance calculations for a bar and a flat disc of thermal conducting material are given in the Appendix.

The equations given in the Appendix however, assume no thermal resistance between the case and the heat sink.

The primary heat conducting surface on stud-mounted SOE packages is the flat metal surface between the actual stud and BeO case body labeled surface S in Figure 2. This surface, which has a D-flat on some case types, must make good contact with the heat sink to allow good thermal conduction. To insure good contact: a) the heat sink mounting surface must be flat, b) the mounting hole must be burr free, the proper size and perpendicular to the mounting surface, c) the proper sized nut should be used and d) the nut should be properly torqued. Recommended mounting hardware is given in the section on device mounting.

With flange-mounted devices the primary parameters affecting thermal transfer are the flatness of the heat sink surface and the flatness of the device flange. The flange-mounted package requires that good contact be made between the flange and the heat-sink surface, particularly directly beneath the BeO disc.

With either of these packages it has been found that a considerable improvement in thermal transfer can be achieved through the proper use of one of the silicone based "heat-sink compounds" which are marketed by several vendors. Dow Corning and Wakefield Engineering are both suppliers of good thermal compounds. It should be pointed out however, that these compounds have a thermal conductivity approximately equal to that of Mica (0.0018 Cal/Sec-cm-$^{\circ}$C) which is poor compared to that of Aluminum (0.49 Cal/Sec-cm-$^{\circ}$C). However by comaprison, the thermal conductivity of still air is approximately 0.000006 Cal/Sec-cm-$^{\circ}$C). The quantity of silicone grease used must be kept to the absolute minimum required to fill in any air gaps which might occur between the transistor mounting surface and the heat-sink surface. In the case of the stud-mounted package this is the gap after the transistor has been secured with the proper stud torque. Contributions of as high as 0.5$^{\circ}$C/watt to the overall thermal resistance can occur if the heat-sink compound is used in a sloppy and excessive manner.

## MOUNTING SOE DEVICES

The second area demanding consideration by a user of SOE transistors is mechanical mounting. Failure to observe proper mounting procedures can result in device destruction. This section will discuss both the stud-mounted, and the flange-mounted SOE devices.

Seven general considerations for properly mounting SOE transistors are listed briefly below. More detailed discussion will follow.

A. The device should never be mounted in such a manner as to place ceramic to metal joints in tension.

B. The device should never be mounted in such a manner as to apply force on the strip leads in a vertical direction towards the cap.

C. When the device is mounted in a printed circuit board with the copper (stud or flange) and BeO portion of the header passing through a hole in the circuit board, adequate clearance must be provided for the BeO to prevent shear forces from being applied to the leads.

D. Some clearance must be allowed between the leads and the circuit board when the device is properly secured to the heat sink.

E. The device should be properly secured into the heat sinks before the device leads are attached (soldered) into the circuit.

F. The leads must not be used to prevent device rotation on stud type devices during stud torque application. A wrench flat is provided for this purpose.

G. With stud packages, maximum stud torque, as stated later in this note, and on the respective device data sheets must not be exceeded. If repeated assembly/disassembly operation is expected, a lesser torque should be used.

Most of the considerations listed above are designed to prevent tension at the metal-ceramic interfaces on the SOE package. Improper mechanical design can lead to application of stresses to these joints resulting in device destruction. Three joints are considered: The cap to the BeO disc, the leads to the disc, and the stud or flange to the disc.

The joint between the ceramic cap and the BeO ceramic disc is composed of a material which loses strength above 175$^{\circ}$C. While the strength of the material returns upon cooling, any force applied to the cap at high temperature may result in failure of the cap to ceramic joint.

The lead frame and stud or flange attachment will be grouped together since they are very similar. Although the SOE package used by Motorola makes use of high temperature ($>$ 700$^{\circ}$C) solder alloys for lead frame and flange or stud attachment, care should be taken to avoid the application of tensile forces to the joint in the mounting of the transistor into a system. Such forces could result if the device were mounted with improper mounting clearances.

## MOUNTING THE STUD TYPE SOE TRANSISTOR

Figure 3 shows a cross-section of a printed circuit board and heat sink assembly for mounting a stud type SOE device. Let us define H as the distance from the top surface of the printed circuit board to the D-flat heat sink surface. If H is less than the minimum distance from the bottom of the lead material to the mounting surface of the SOE

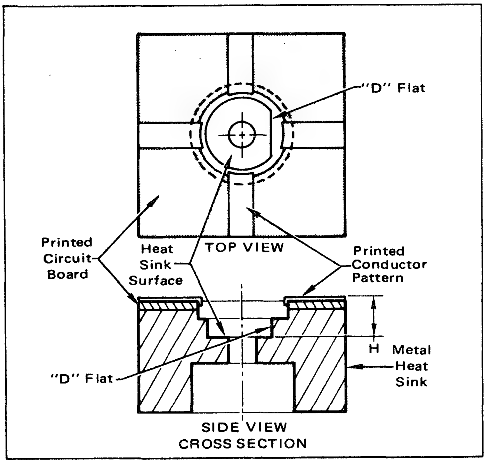



**FIGURE 3 – Typical Stud-Mounting Method**

package, there is no possibility of tensile forces in the copper stud – BeO ceramic joint. If, however, H is greater than the package dimension, considerable force is applied to the cap to BeO joint and the BeO to stud joint. Two occurances are possible at this point. The first is a cap joint failure when the structure is heated, as might occur during the lead soldering operation; while the second is BeO to stud failure if the force generated is high enough. Lack of contact between the device and the heat sink surface will occur as the difference between H and the package dimension becomes larger, this may result in device failure as power is applied.

Proper stud torque is an important consideration when mounting stud type SOE devices.* The stud section of the SOE package is composed of a special copper alloy chosen because of its high thermal conductivity. However when this material is used in studded semiconductor device packages, it is necessary to place severe restrictions on the amount of tightening torque which can be applied to a nut used to secure the device to a heat sink.

*The Motorola Outline Dictionary calls for Class 2A threads. The National Bureau of Standards Handbook H28 entitled Screw Thread Standards, paragraph 4.2 on page 2.17, reads in part as follows:

> "However, for threads with additive finish, the maximum diameters of Class 2A threads may be exceeded by the amount of the allowance; i.e., the 2A maximum diameters apply to an unplated part or to a part before plating whereas the basic diameters (the 2A maximum diameter plus allowance) apply to a part after plating."

Also, footnote b, page 2.37 reads:

> "For Class 2A threads having an additive finish, the maximum is increased to the basic size, the value being the same as for Class 3A."

This means that for plated parts, the no-go gauge used is the 2A minimum and the go gauge used is the 2A maximum plus the allowance or, in other words, the 3A maximum.

The recommended torque values are listed below for the two thread sizes presently being employed on Motorola rf power transistor packages.

Recommended maximum torque for stud SOE transistors follows:

| | 8 - 32 Threads | 10 - 32 Threads |
|---|---|---|
| One time maximum | 6.5 lb.-in. | 11.0 lb.-in. |
| Repeated assembly-assembly maximum | 5.0 lb.-in. | 8.5 lb.-in. |

An evaluation of the effects of measured torque on the studs under consideration requires a known set of conditions. The system used to generate the data shown in Figure 4 consisted of a 1/8 inch aluminum plate with a deburred clearance hole for the stud under test, a steel washer to be positioned between the plate and appropriate steel nut. A calibrated torque wrench was used as the driving means. On each unit under test, the spacing separating four threads positioned between the nut and heat-sink surface was measured. After mounting the device on the aluminum plate and applying a known amount of torque the spacing was again measured and the results recorded.

The results of this test show that up to the maximum torque specified, the permanent elongation of the threads increases linearly with applied torque. At the torque specified this elongation does not exceed acceptable limits.

### MOUNTING THE FLANGE TYPE SOE TRANSISTOR

The mounting and heat sinking of the flange type package is similar to that of the stud type package. The main considerations with the flange package are avoiding tensile stresses at the metal-ceramic joints and providing a flat heat conducting surface beneath the flange.

Figure 5 shows a typical mounting technique for flange type SOE rf power transistors. Again H is defined as the distance from the top of the printed circuit board to the heat-sink surface. If distance H is less than the minimum distance from the bottom of transistor lead to the bottom surface of the flange, tensile forces at the various joints in the package are avoided. However, if distance H exceeds the package dimension, problems similar to those discussed for the stud type devices can occur. Because of the ability

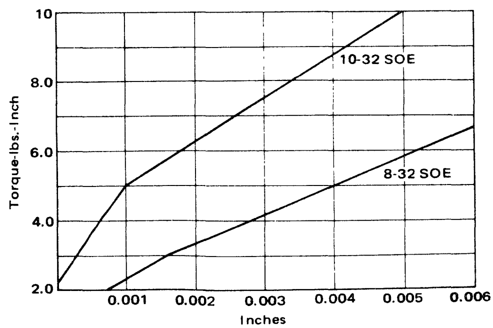



**FIGURE 4 – Permanent Elongation Over a Four Tooth Length**

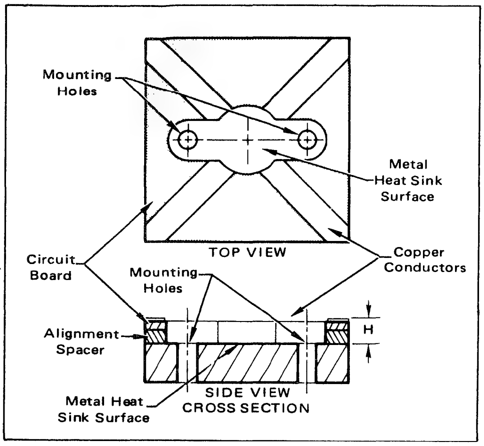



**FIGURE 5 — Flange Type SOE Transistor Mounting Method**

of the copper flange to bend under the types of loads encountered when the mounting screws are tightened, permanent deformation of the flange may result. Corrective action after the flange has been bent will not necessarily insure proper thermal contact with the heat sink.

The flange surface as supplied with Motorola SOE transistors is either flat or slightly convex. It is important that the mating heat-sink surface also be flat or slightly convex to provide the best contact when the device is properly secured.

The holes for the mounting screws should be deburred because any irregularity of the surface at these two points is equivalent to concavity of the heat-sink surface which will degrade thermal contact between the transistor and the heat sink.

Since the flange may be permanently deformed during mounting, the device should not be dismounted and remounted in another position.

## CONCLUSION

The SOE package is an excellent rf power transistor package. However, improper heat sinking and mechanical mounting can result in device damage. A number of considerations have been presented to inform the potential user of the hazards of improper mounting. Proper usage of the SOE package requires no great difficulty if the designer is aware of the limitations and construction of the package.

A list of recommended mounting hardware and a suggested mounting procedure follows:

**Table of Recommended Mounting Hardware Which Can be Supplied With Motorola Stud Type SOE Transistor**

| Stud Thread Size | Motorola Part Numbers | | |
|---|---|---|---|
| | Nut | Flat Washer | Lock Washer |
| 10-32 | 02BSB51568F044 | 04BSB51567F040 | 04BSB51566F028 |
| 8-32 | 02BSB51568F042 | 04BSB51567F038 | 04BSB51566F030 |
| 6-32 | 02BSB51568F040 | 04BSB51567F036 | 04BSB51566F032 |

## STEPS IN A PROPER MOUNTING PROCEDURE

1. Compare the distance between the heat sink surface and the top of the printed circuit board with the minimum dimension of the transistor from the mounting surface to the bottom of the leads. The transistor dimension, as stated on the device data sheet, should be the greater distance to avoid the chance of stresses on the various joints of the SOE package.

2. Bore the proper sized mounting hole or holes for the stud or mounting screws. These holes should be perpendicular to the heat sink surface and they should be properly deburred.

3. Place a limited amount of thermal compound on the heat sink surface where it will contact the flange or mounting surface above the stud. Insert the transistor and mount with the proper hardware as suggested in the preceeding table.

   In the case of the stud device, torque the nut to the proper value.

4. Solder the leads to the printed circuit board using the minimum amount of heat and the least possible time of application. The leads should be soldered as close to the package as possible to minimize series lead inductance.

5. With the unit exposed to the highest expected ambient temperature, and power applied, measure the temperature at the stud or flange surface with a thermocouple to insure that this temperature is not excessive. Before production quantities are commited, it is suggested that a sample assembly to be tested under worst case heat generating conditions.

## APPENDIX

In order to aid in heat-sink design, a table of thermal properties of common materials and a pair of thermal conductivity examples are presented.

Table AI gives three important thermal properties of common heat-sink materials. In order to evaluate materials for use in heat sinks these three thermal properties should be considered.

**Thermal conductivity** is a measure of the ability of a material of known cross-sectional area to transfer heat a given distance in a given time with a given temperature difference. Generally metals are good thermal conductors.

**Specific heat** is a measure of the amount of heat a given mass of material can accept for a given rise in temperature. The scale is normalized to the heat capacity of water ($H_2O$ = 1.0).

**Mass density** is simply the mass per unit volume of a material. This parameter is important in heat sink design to the extent that large heat sinks of dense material carry with them a serious weight penalty.

**TABLE AI – Typical Thermal Properties of Materials**

| Material | Thermal Conductivity K (cal/sec-cm-$^{o}$C) | Specific Heat S (cal/gm-$^{o}$C) | Mass Density $\rho$ (gm/cm$^{o}$C) |
|---|---|---|---|
| Silver | 0.97 | 0.056 | 10.5 |
| Copper | 0.92 | 0.093 | 8.9 |
| Gold | 0.69 | 0.030 | 19.3 |
| Beryllia-Ceramic | 0.55 | 0.31 | 2.8 |
| Aluminum | 0.49 | 0.22 | 2.7 |
| Brass | 0.26 | 0.094 | 8.6 |
| Silicon | 0.20 | 0.18 | 2.4 |
| Germanium | 0.14 | 0.074 | 5.5 |
| Steel | 0.12 | 0.12 | 7.8 |
| Solder | 0.09 | 0.04 | 8.7 |
| Kovar | 0.046 | 0.11 | 8.2 |
| Alumina-Ceramic | 0.04 | 0.21 | 3.7 |
| Plastic-Epoxy | 0.0026 | 0.2 | 2.0 |
| Glass | 0.0026 | 0.20 | 2.2 |
| Mica | 0.0018 | 0.20 | 3.2 |
| Teflon | 0.00056 | 0.25 | 2.2 |
| Air | 0.000057 | 0.24 | 0.0013 |
| Heat Sink Compound | 0.0018 | – | – |

**Example 1.**

In order to present some of the important characteristics to be used in heat sink design, the examination of two admittedly simplified models is desirable. The analogy between electrical resistivity and thermal resistivity will be employed.

The first of these is shown in Figure A1.

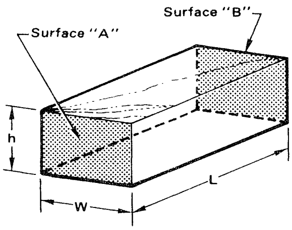



**FIGURE A1 – A Bar of Thermal Conducting Material**

The electrical resistance from Surface A to Surface B of this bar of conductive material is:

$$R = \frac{\rho L}{hW} \qquad \text{(A1)}$$

Using the electrical to thermal analogs:

$$\theta = \frac{L}{KhW} = \frac{L}{KA} \qquad \text{(A2)}$$

This simplified model might represent a pedestal mount or a device mount in the center of a bar connecting at either end to a housing, and demonstrates the need for thermally conducting paths of high cross-sectional area and the shortest possible length.

**Example 2.**

The second simple model represents the mounting of the power device on a plate of conducting material which provides the conducting path to the ambient conditions.

Consider the simple disc geometry shown in Figure A2 as a donut-shaped sheet resistor. Equation A3 represents the electrical resistance between r1 and r2,

$$R = \frac{\rho}{2\pi x} \ell n\left(n \frac{r2}{r1}\right) \qquad \text{(A3)}$$

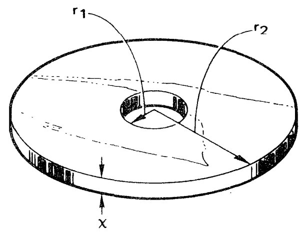



**FIGURE A2 – Disc-Shaped Thermal Conductor**

using the first term of the appropriate power series expansion

$$R \approx \frac{\rho}{\pi x}\left(\frac{r2 - r1}{r2 + r1}\right). \qquad \text{(A4)}$$

Where: $\rho$ = Resistivity;

$\rho = \frac{1}{\sigma}$;

$\sigma$ = Conductivity.

Replacing the electrical terms with their thermal analogs we find:

$$\theta = \frac{1}{K\pi x}\left(\frac{r2 - r1}{r2 + r1}\right)$$

Note the inverse linear dependence of thermal resistance on the thickness of the conducting sheet.

This model demonstrates a major factor in designing heat sink structures for stud type power transistors. All other factors being equal, the thickness of the thermally conducting plate is of prime importance in the solution of heat flow problems.

# SEMICONDUCTORS NOISE FIGURE CONSIDERATIONS

## INTRODUCTION

The design of low noise amplifiers requires a basic working knowledge of subjects such as circuit stability, cross modulation, noise figure, etc.

The purpose of this report is to provide, in a single working reference, basic semiconductor noise figure considerations. Emphasis is on basic fundamentals rather than complex mathematical derivations. Because much of the theory, particularly with noise, is statistical and quite complicated, derivations will in fact be avoided with details available in suggested references.

## NOISE SOURCES

The three types of noise sources generally associated with solid state devices are thermal noise, shot noise and excess noise.

THERMAL NOISE – Thermal noise[1,2,6,7,16] results from the random motion of free carriers in a medium caused by thermal agitation. Although the sum of all the noise currents over a long period of time is zero, at any given instant a net current in one direction may result. In an ideal resistor, the net current produces a voltage which has a constant spectral density independent of frequency. The self-generated noise voltage across a resistor is:

$$e_n = \sqrt{4\,k\,T\,R\,B},$$

where:

$e_n$ = Johnson noise (rms volts)

k = Boltzmann's constant ($1.38 \times 10^{-23}$ joule/$^{o}$k)

T = Temperature (degrees Kelvin)

R = Effective Resistance (Ohms)

B = Equivalent bandwidth (Hz) of the system through which the noise is measured.

The thermal noise associated with a solid state device results from resistance within the device. Thermal noise in a transistor comes principally from the base spreading resistance ($r_b'$).

SHOT NOISE – Shot noise[2,6,7,16], and thermal noise for that matter, depends on the nature of charge carriers for generation. The basic difference, is that thermal noise is produced by the erratic movement of free charge while shot noise is produced by the change (i.e., appearance and disappearance) of the charge carriers with respect to the circuit current.

The basic equation for full shot noise in a diode is:

$$i_n = \sqrt{2q\,I_{dc}\,B}$$

where:

$i_n$ = shot noise (rms amps)

q = electron charge ($1.59 \times 10^{-19}$ coulombs)

$I_{dc}$ = diode direct current (amps)

B = equivalent bandwidth (Hz)

Another important characteristic of both thermal and shot noise is the flat frequency spectrum. This frequency independent characteristic is an important consideration in the construction of equivalent device noise models.

Sources of shot noise in a transistor are currents within the emitter-base and collector-base diodes.[5]

EXCESS NOISE – Excess noise[2,14,16] usually occurs at low frequencies and is also known as 1/f noise. The exact mechanism producing this phenomenon is not well known. It is thought to be associated with "traps" within the emitter depletion layer which capture and release carriers at different frequency rates but with energy levels varying inversely with frequency. This noise is not only present in junction transistors and field-effect transistors, but also in certain types of resistors.[1,2] In general, the excess noise in junction transistors and field-effect transistors is negligible above 1 kHz.[4]

## NOISE FIGURE

The sensitivity of an amplifier is limited by the signal-to-noise ratio available at the antenna or input. The presence of any of the previously described noise sources within the system only serves to further deteriorate this ratio. The amount of deterioration of the available input signal-to-noise ratio is called the noise figure and may be defined as:

$$F = \frac{\frac{P_{si}}{P_{ni}}}{\frac{P_{so}}{P_{no}}} = \frac{P_{no}}{P_{ni}}\,\frac{1}{G}, \qquad (1)$$

where:

F = noise figure in power ratio

$P_{si}$ = signal input power

$P_{ni}$ = noise input power

$P_{so}$ = signal output power

$P_{no}$ = noise output power

G = power gain of system

Noise figure is generally expressed in decibels, i.e.:

$$F_{(dB)} = 10 \log_{10} \left( \frac{P_{no}}{G\, P_{ni}} \right) \quad (2)$$

From a practical standpoint, a distinction needs to be made between two types of noise figure, "Spot noise figure"[3,4] and "average noise figure."[3] Spot noise figure is the noise figure measured in a narrow frequency band, useful for specifying the noise figure at individual frequencies. Average noise figure is measured over a particular frequency spectrum such as the bandwidth of an IF amplifier and is useful when specifications approximating total system performance are required.

GENERAL CHARACTERISTICS – A discussion of noise figure variations versus frequency for all types of semiconductor devices is a complex study and actually beyond the scope of this paper. On the other hand, a preliminary study of transistor noise figure versus frequency can cover several general points which are common with other device types. A study of this type usually utilizes an equivalent circuit involving device parameters and noise sources from which noise figure is derived. The complexity of the resultant noise figure expression will vary with the complexity of the equivalent circuit used. A relatively simple yet adequate noise figure expression for this purpose is Nielsen's equation.[5,6,7,8] A modified version of this expression is:

$$F = 1 + \frac{r_e}{2R_g} + \frac{r_b'}{R_g} + \left[\frac{(R_g + r_e + r_b')^2}{2\beta_o R_g r_e}\right]\left[1 + (\beta_o + 1)\left(\frac{f}{f_{ab}}\right)^2\right] \quad (3)$$

where:

$r_e = \dfrac{26}{I_{E\,(mA)}}$ (ohms)

$r_b'$ = base spreading resistance (ohms)

$R_g$ = source resistance (ohms)

$\beta_o$ = low frequency common emitter current gain

f = frequency (Hz)

$f_{ab}$ = common base cut-off frequency (Hz)

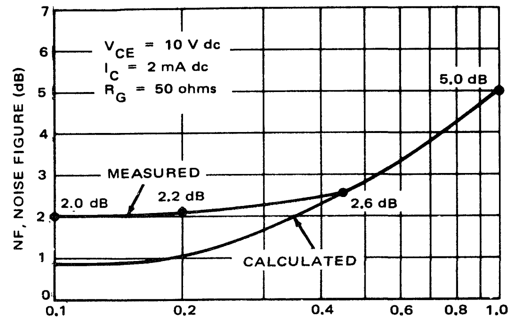



**FIGURE 1 – TYPICAL SPOT NOISE FIGURE versus FREQUENCY (CALCULATED AND MEASURED) FOR 2N4957 SILICON PNP TRANSISTOR**

The graph in Figure 1 gives both the measured and calculated curves of noise figure versus frequency for the 2N4957 transistor. Generally, the measured curve is flat in the mid-frequency range, increasing at approximately 6 dB per octave at higher frequencies. The descrepancy between measured and calculated values of noise figure in the mid-frequency range results from either not considering all noise sources or not properly analyzing the assumed noise sources. Regardless, the noise model used is reasonably accurate and adequate for the purpose of this paper.

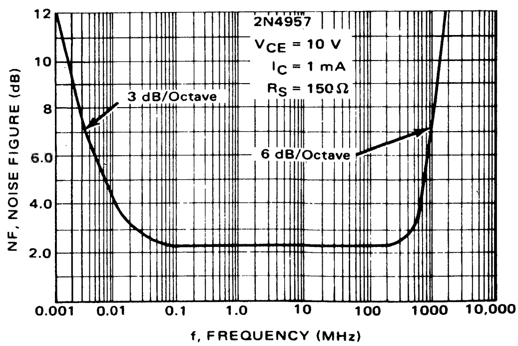



**FIGURE 2 – NOISE FIGURE ASYMPTOTES**

Transistor noise figure at low frequencies (1 kHz or less) is not predicted by Nielsen's equation. The major noise contributor in this region is excess noise. The slope of the curve in this lower frequency is approximately -3 dB per octave. Figure 2 shows a typical noise figure versus frequency curve for the 2N4957 which includes the region affected by excess noise.

Although equivalent noise circuits vary depending on device type (such as junction and MOS FETs) the same general characteristic noise figure versus frequency curve exists for each (see figures 3, 4, 5, 6 and 7).

Other important noise figure characteristics are evident from equation 3. For example, for a given transistor of known device parameters and operating frequency, this equation describes the relationship of noise figure versus source resistance. [5,9] Closer examination indicates that by proper selection of source resistance, noise figure can be minimized. A similar dependence may also be noted between noise figure and bias conditions—particularly emitter current.

An additional design variable of importance that is not shown by equation 3 is the source susceptance. [10] For many high frequency devices, lower noise figures are attained by mis-tuning the input circuit rather than tuning for maximum gain—that is, the base (common-emitter configuration) sees a resistance shunted by a susceptance (usually capacitive). The value of this susceptance is found by empirical methods. Again, the considerations are true with junction and MOS field-effect transistors. That is, the noise figure, in general, is optimum for a particular bias point and source admittance.

### CHARACTERIZING THE DEVICE

Noise figure curves from device data sheets take several forms. One of the simplest presentations is noise figure versus frequency at a fixed bias point (see Figure 5). This bias point is usually a compromise between minimum noise figure and maximum power gain. Curves of this type, as a rule, do not provide the optimum source resistance necessary for minimum noise figure.

A convenient method of showing source resistance variations for a fixed frequency is shown in Figure 8. This figure shows at a glance the optimum source resistance for

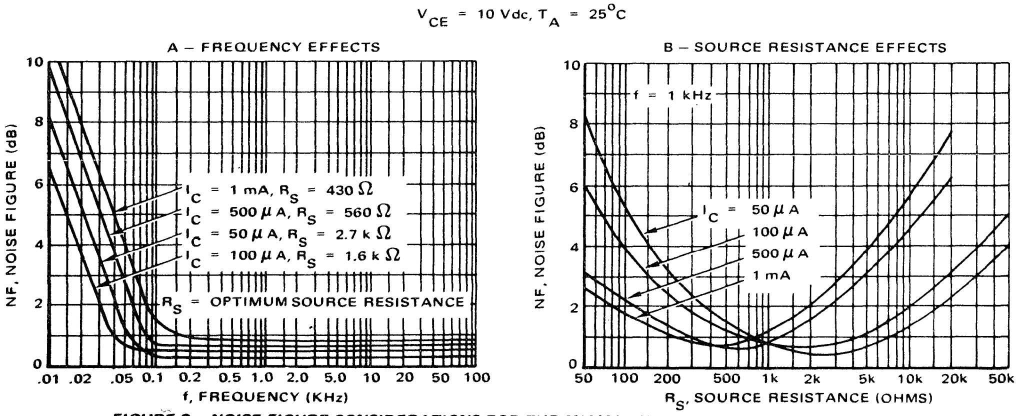



**FIGURE 3 – NOISE FIGURE CONSIDERATIONS FOR THE 2N4402 AND 2N4403, SILICON PNP TRANSISTORS**

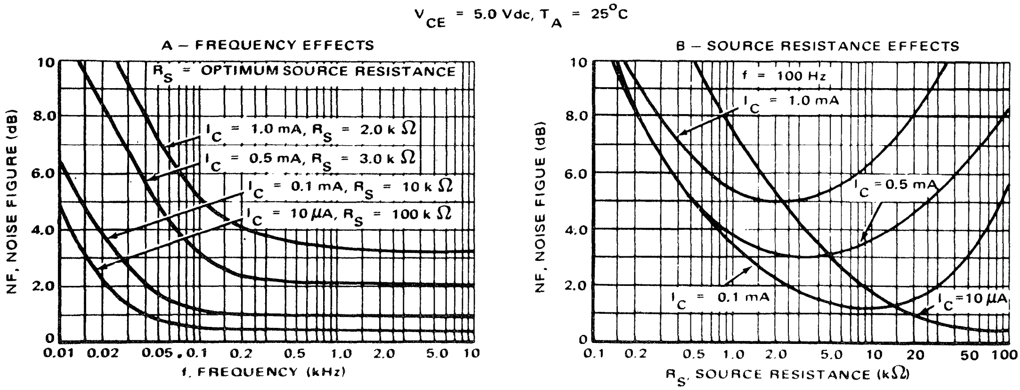



**FIGURE 4 – NOISE FIGURE CONSIDERATIONS FOR THE 2N5088 AND 2N5089, SILICON NPN TRANSISTORS**

various values of collector current. Similar curves (see Figure 10) at other frequencies allow a more complete picture of noise figure to be made.

Another method of demonstrating source resistance effects is shown in Figure 4B. Here the noise figure is plotted versus source resistance for several values of bias current. This presentation is common for low frequency devices. Another presentation which usually incorporates the previous curve is shown in Figure 4A. This figure shows noise figure versus frequency for several values of collector current. Each value of collector current includes the optimum source resistance for this value of current. The optimum source resistance is usually taken from a figure similar to Figure 4B.

An example of a field-effect transistor presentation similar to Figure 4 is shown in Figure 6 for a junction field-effect and Figure 7 for a tetrode connected junction field-effect transistor.

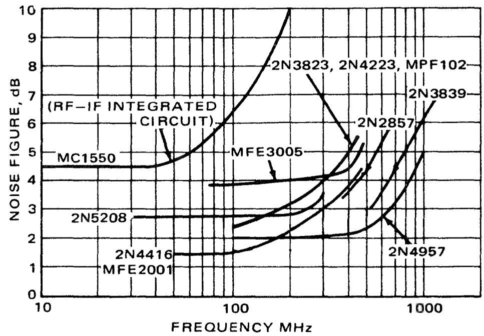



**FIGURE 5 – NOISE FIGURE versus FREQUENCY FOR VARIOUS RF SEMICONDUCTOR DEVICES**

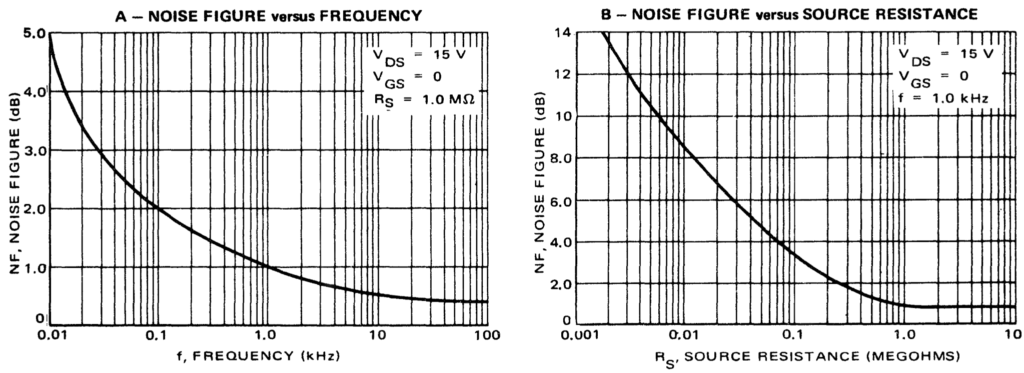



**FIGURE 6 – NOISE FIGURE versus FREQUENCY FOR THE 2N4220, J-FET**

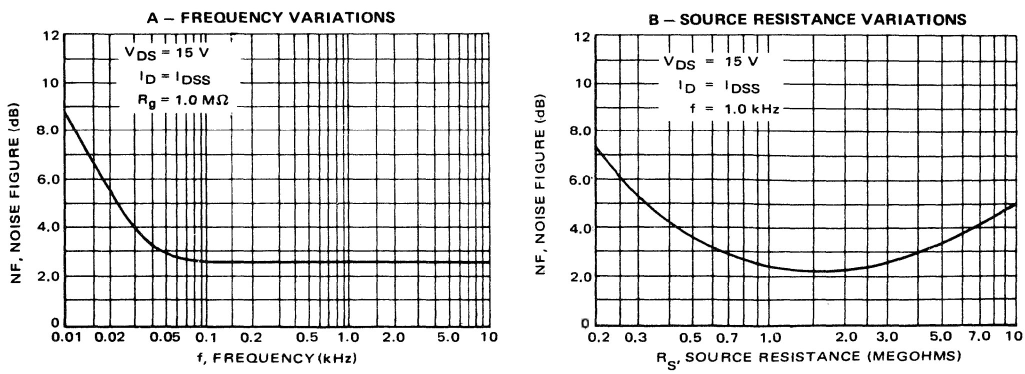



**FIGURE 7 – NOISE FIGURE versus SOURCE RESISTANCE FOR THE 3N124, TETRODE J-FET**

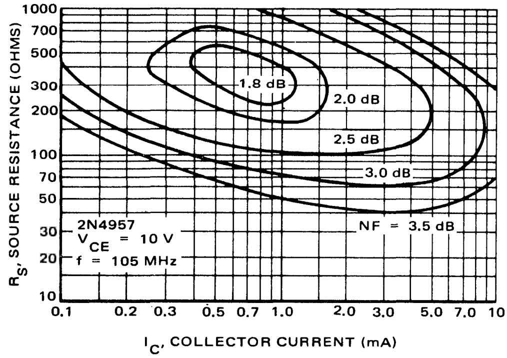



**FIGURE 8 – CONTOURS OF NOISE FIGURE versus SOURCE RESISTANCE AND COLLECTOR CURRENT FOR 2N4957 AT 105 MHz**

## LOW FREQUENCY NOISE FIGURE MEASUREMENTS

SIGNAL GENERATOR METHOD – One of the simplest methods for measuring noise figure at low frequencies is to fix the input signal-to-noise ratio, and note the resultant output signal-to-noise ratio. The resultant degradation in the output signal-to-noise ratio (noise figure) may be expressed in the following form:

$$F_{(dB)} = 20\log_{10}\left(\frac{E_{si}}{E_{ni}}\right) - 20\log_{10}\left(\frac{E_{so}}{E_{no}}\right), \qquad (4)$$

where:

$E_{si}$ = signal input voltage

$E_{ni}$ = noise input voltage

$E_{so}$ = signal output voltage

$E_{no}$ = noise output voltage

(For measurement purposes the signal levels are expressed in terms of voltage rather than power.) If the source resistance $R_s$ is known, $E_{ni}$ can be calculated from equation (1) and $E_{si}$ adjusted so the input signal to noise ratio is a convenient value such as 20 dB.

For such a case:

$$F_{1(dB)} = 20\text{ dB} - 20\log_{10}\left(\frac{E_{so}}{E_{no}}\right) \qquad (5)$$

Since the measured output signal also includes $E_{no}$, the actual signal measured is:

$$\sqrt{E_{so}^2 + E_{no}^2}\ \dagger$$

Substituting the measured output signal into equation (5), the original relation becomes:

$$F_{2(dB)} = 20\text{ dB} - 20\log_{10}\frac{\sqrt{E_{so}^2 + E_{no}^2}}{E_{no}} \qquad (6)$$

The difference between equation (5) and equation (6) represents the degree of error involved:

$$F_{1(dB)} - F_{2(dB)} = 20\log_{10}\sqrt{\frac{E_{so}^2}{E_{no}^2}+1}$$

$$- 20\log_{10}\frac{E_{so}}{E_{no}} \qquad (7)$$

† A vector sum is necessary as different frequencies are added.

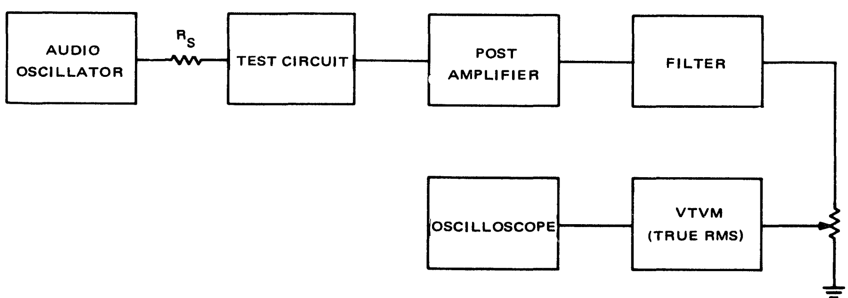



**FIGURE 9 – TEST SET-UP FOR LOW FREQUENCY NOISE FIGURE MEASUREMENT–SIGNAL GENERATOR METHOD**

As an example, this difference or error is less than 0.5 dB for a device having a noise figure up to 10 dB if the input signal to noise ratio is 20 dB.

The general procedure (see Figure 9) for utilizing this method is as follows: First, adjust the input voltage signal to noise ratio to 20 dB. Second, adjust the variable attenuator such that the voltmeter indication of $E_{so}$ is full scale. Next, reduce the input signal to zero and note the drop in output voltage (dB). Since the output voltage without a signal is $E_{no}$, the actual drop in output in dB represents the ratio of $E_{so}$ and $E_{no}$. This ratio, when subtracted from 20 dB, is the noise figure (without error correction).

### CONSTANT-GAIN METHOD

The basis for this method involves maintaining a constant known voltage gain and measuring $E_{no}$ (see equation 8). Knowing these terms, in addition to the bandwidth (which is determined by a band-pass filter as in the first method) and the source resistance, the noise figure can be calculated. A commercial instrument employing this operating principle is the Quan-Tech Noise Analyzer, Model 2173-2181.

$$F = \frac{P_{no}}{P_{ni}} \quad \frac{1}{G}, \quad G = \text{power gain}$$

or, in terms of voltage:

$$F = \frac{E_{no}^{\ 2}}{E_{ni}^{\ 2}\,(G_V)^2}\ ; \tag{8}$$

where $G_V$ = voltage gain.

### HIGH FREQUENCY NOISE FIGURE MEASUREMENTS

OUTPUT DOUBLING METHOD – Probably the simplest technique to measure noise figure at high frequencies is the noise doubling method. This involves increasing the noise generator output until the noise power in the output is doubled. The noise power produced by the noise generator under these conditions is the same as that produced by the circuit. That is:

$$P_{no} = G\,P_{ng},$$

where:

$P_{no}$ = noise power out from source and device

$G$ = power gain

$P_{ng}$ = noise generator power output

If this term is substituted into equation (2), we have the following expression:

$$F = \frac{P_{ng}}{P_{ni}} \tag{9}$$

The actual values of both $P_{ng}$ and $P_{ni}$ are functions of not only source resistance but also the input impedance of the "device-under-test" circuit. A convenient method of defining $P_{ng}$ and $P_{ni}$ is on an available power basis, or,

$$P_{ni} = \frac{e_{ni}^{\ 2}}{4\,R_g}\ , \tag{10}$$

and

$$P_{ng} = \frac{i_{ng}^{\ 2}\,R_g}{4} \tag{11}$$

For the case where the noise generator used is a temperature-limited tungsten-filament diode with a mean-square current of

$$i_{ng} = 2q\,I_{dc}\,B \text{ (see shot noise)} \tag{12}$$

$$F = \frac{q\,I_{dc}\,R_g}{2\,k\,T_o} \tag{13}$$

Assuming the temperature of the source ($T_o$) is 290°K and that $R_g$ is 50 ohms, this expression reduces to:

$$F = I_{dc} \text{ (in mA)}. \tag{14}$$

The actual technique used to double the noise output power involves more than connecting an RF voltmeter to the output of the test circuit and noting when the twice power output point is reached. First, the noise power levels are very low and a post amplifier is required to increase these levels to the capability of the RF voltmeter. In addition, this power amplifier (if spot noise is desired) must have a bandwidth less than the test amplifier and must not overload for the signal levels encountered. Finally, the actual RF voltmeter used must be linear and must respond to the RMS voltage.

The contribution of noise by the post amplifier is taken into account by the following equation:

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1\,G_2} \cdots \frac{F_{(n-1)}}{G_1\,G_2 \ldots G_{(n-1)}}, \tag{15}$$

where,

$F$ = overall noise figure (power ratio)

$F_1$ = noise figure of the first stage (power ratio)

$F_2$ = noise figure of the second stage (power ratio)

$F_3$ = noise figure of the third stage (power ratio)

$G_1$ = power gain of the first stage (ratio)

$G_2$ = power gain of the second stage (ratio).

Additional considerations, such as "image response", are beyond the scope of this paper. For more information on these considerations, see references 18, 19, and 25.

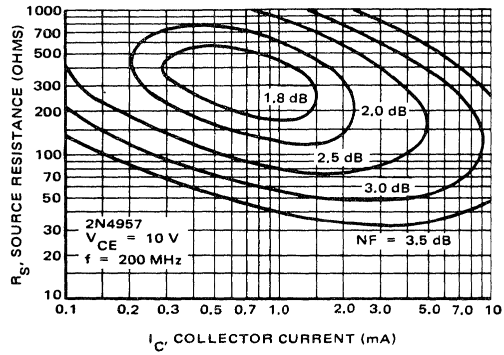



**FIGURE 10 – CONTOURS OF NOISE FIGURE *versus* SOURCE RESISTANCE AND COLLECTOR CURRENT AT 200 MHz**

COMMERCIAL EQUIPMENT TECHNIQUE – More sophisticated noise measurement techniques generally use a noise generator with two modes of operation. One mode utilizes the output power from a source such as a temperature limited diode or a gas-discharge tube. The second mode usually utilizes the noise output power of the generator source resistance at room temperature.

A noise generator of this type is connected to the input of a system under test and the two resultant output levels from the "system" are used to determine the noise figure (See Figure 12). The general equation[17] relating noise figure and the two output levels is:

$$F = 10 \log_{10}\left[\frac{T_2 - T_o}{T_o}\right] - 10 \log_{10}\left[\frac{P_{no2}}{P_{no1}} - 1\right] \quad (16)$$

where the expression $[(T_2 - T_o)/T_o]$ is a measure of the relative excess noise power from the noise generator and $P_{no1}$ and $P_{no2}$ are the two resultant power output levels. These levels correspond respectively to the "fired" and "unfired" modes of operation of the noise source.

The relative excess noise power is usually specified by the manufacturer. A typical value for an Argon gas tube is 15.2 dB. However, for accurate measurements, each source must be individually checked at each frequency of intended use.

Equation (16) is the basis for several of the most popular manual and automatic commercial noise characterization systems.[17,18,19]

A typical manual noise figure system using an IF attenuator is shown in Figure 11. The objective in using the attenuator is to determine the ratio of $P_{no1}$ and $P_{no2}$. This ratio is called the "Y" factor. Initially, a convenient detector level is noted with the noise diode in the unfired mode. Next, the noise diode is fired and the attenuator readjusted to reduce the new detector level to the original level. The amount of attenuation added is the ratio of $P_{no2}$ to $P_{no1}$. The resultant noise figure is calculated by substituting the excess noise power and the attenuator change in equation (16).

Automatic noise measuring equipment in general, gate the noise diode "on" and "off" at a fixed rate and continuously record the output power ratio. Methods of reducing this ratio to a continuous noise figure reading will vary with manufacturer.

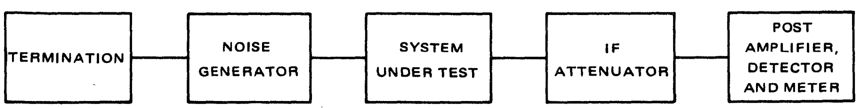



**FIGURE 11 – MANUAL NOISE FIGURE SYSTEM USING AN IF ATTENUATOR**

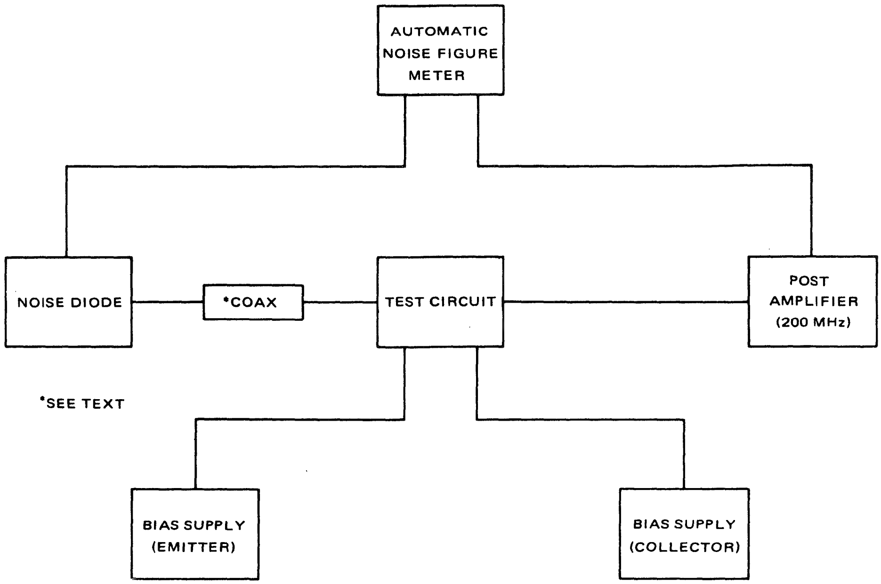



**FIGURE 12 – TYPICAL TEST SET-UP FOR 200 MHz NOISE FIGURE MEASUREMENT**

## TYPICAL VHF NOISE FIGURE MEASUREMENTS USING AUTOMATIC EQUIPMENT

A typical 200 MHz noise figure test set-up using automatic noise measuring equipment is shown in Figure 12.

The noise diode is connected to the test circuit through a special coaxial cable which transforms the 50 ohm noise diode impedance to a higher impedance level, (such as 100 ohms) with negligible circuit loss. Input circuit losses are important since each dB of input circuit loss adds directly to the noise figure. The special coaxial cable length is trimmed to exactly one-quarter of a 200 MHz wavelength, such that when one end of the cable is terminated in 50 ohms, the resultant impedance level at the other end is the desired resistive value with minimum shunting capacitance (0.2 pF max). The cable characteristic impedance necessary to give the desired source resistance is calculated from:

$$R_o^2 = R_S R_L,$$

where

$R_o$ = characteristic impedance of cable (ohms)

$R_L$ = resistance of noise diode (50 ohms)

$R_S$ = desired source resistance (ohms)

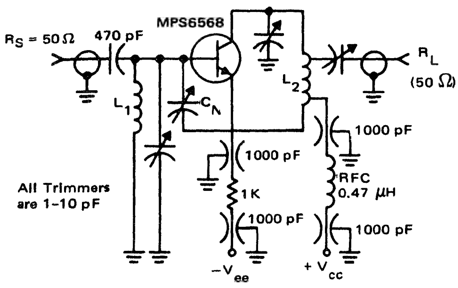
Several values of source resistance values are readily attained by using coaxial cable with standard values of characteristic impedance. Additional resistance values can be attained by varying the center-conductor wire size of the cable.

Directly following the test amplifier is the post amplifier. This amplifier provides the additional gain necessary to operate the automatic noise figure equipment. Although the required gain is also a function of the test circuit gain, a typical power gain is 50 dB.

Since system bandwidth is determined by the automatic noise equipment, no special bandwidth restrictions are required.

Any contribution of the post amplifier to the total measured noise figure may be calculated with Equation 15. A post amplifier with a noise figure low enough to avoid any significant contribution to the total noise figure is highly desirable.

The input impedance of the post amplifier should be 50 ohms since this impedance level will provide the load for the test circuit. If the device under test is mismatched at the output, the resultant source resistance seen by the post amplifier can increase to several hundred ohms and may result in instability problems with the post amplifier. Consequently, the first stage of the post amplifier should be stable regardless of the source resistance.




$L_1$ = 3 TURNS NO. 18 TINNED WIRE, 1/4 INCH I.D. AIR WOUND – LENGTH IS 3/16 INCH.

$L_2$ = 5 1/2 TURNS NO. 16 TINNED WIRE, 3/8 INCH I.D. AIR WOUND – LENGTH IS 1/2 INCH. $V_{cc}$ FEEDS TAP 2 1/2 TURNS FROM COLLECTOR END – OUTPUT TAP, 1/2 TURN FROM COLLECTOR END.

**FIGURE 13 – A TYPICAL 200 MHz NOISE TEST CIRCUIT**

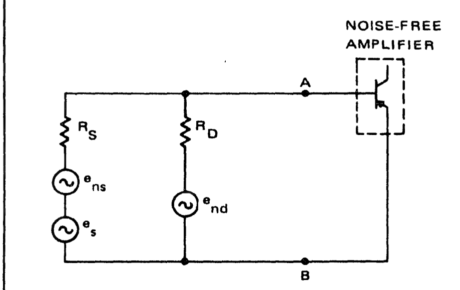



**FIGURE 14 – MODEL TO DEMONSTRATE THE EFFECT OF AN EXTERNAL SHUNT RESISTANCE AT INPUT OF NOISE FIGURE TEST CIRCUIT**

A typical 200 MHz noise figure test circuit is shown in Figure 13. Here a common emitter neutralized configuration is used with two bias supplies. The desired source impedance seen by the device under test is provided by the special coaxial cable previously discussed, and the input tank circuit provides the necessary tuning. The coil ($L_1$) must be carefully constructed to minimize input circuit loss; not only should the unloaded Q be high, but the actual inductance value should be as large as possible and still maintain tuning.

In general, all lead lengths should be minimum and circuit layout should be such that the neutralizing capacitor ($C_N$) is provided the shortest path between the base and $L_2$, through a small hole in the shield. Piston-type capacitors are recommended for $C_N$.

The immediate area should be carefully examined for unknown noise generators. A screen room is certainly a "must." As a general statement, each piece of equipment in the screen room must be examined as a potential noise source. For instance, it is not uncommon to find that the signal generator used to measure power gain, generates a considerable amount of noise power even with the generator output power level reduced.

## DESIGN CONSIDERATIONS FOR HIGH FREQUENCY LOW NOISE AMPLIFIERS

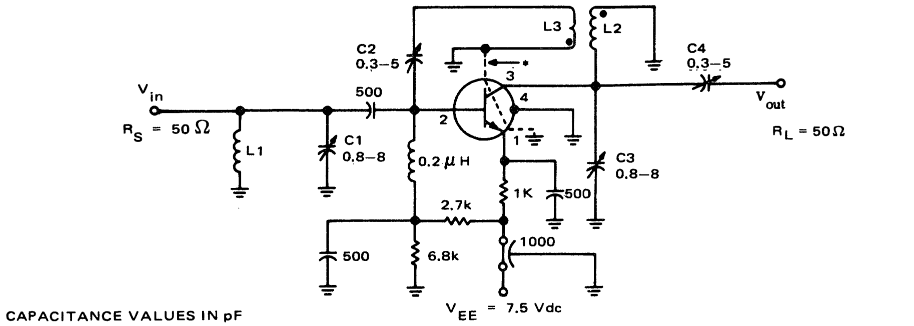
The actual design of a low noise amplifier whether intended for audio or RF applications usually involves considerations other than low noise figure. Particularly in high frequency applications, considerations such as cross-modulation, intermodulation distortion and dynamic range are of paramount importance and may often overshadow and delegate to a secondary role the overall noise figure. (The interested reader may obtain more information in references 10, 23, and 24).

As previously mentioned, the device must operate under specified bias conditions and generator source admittance to realize the optimum device noise figure. In addition to providing the device with this environment, another major noise contributor, input circuit loss, must also be considered. This circuit loss usually takes the form of an equivalent input shunting resistance resulting from coil loss, bias resistance, capacitor loss, or other component losses such as stand-offs and sockets.

An excellent method of demonstrating the effect of an external resistance shunting the input circuit is to consider the circuit in Figure 14. The amplifier is considered noise free. The calculated noise figure [15] up to point A-B is:

$$F = 1 + \frac{R_S}{R_D}$$

For the case where the shunting resistor $R_D$ equals the source resistance, the noise figure will be degraded 3 dB before the device is even considered. The minimum noise figure occurs when $R_D \gg R_S$ which means that $R_D$ must be large or $R_S$ small. The former condition may be difficult to achieve since the input of the amplifier is generally a tuned circuit and the maximum value of $R_D$ (considering the tuned circuit only) will be limited by practicable coil losses. Correspondingly, $R_S$ may not be arbitrarily reduced since the device requires a certain source resistance for minimum noise figure.



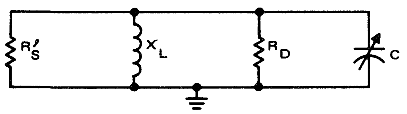

L1, L2 – SILVER-PLATED BRASS ROD, 1-1/2" LONG AND 1/4" DIAMETER. INSTALL AT LEAST 1/2" FROM NEAREST VERTICAL CHASSIS SURFACE.

L3 – 1/2 TURN NO. 16 AWG WIRE; LOCATED 1/4" FROM AND PARALLEL TO L2

* – EXTERNAL INTERLEAD SHIELD TO ISOLATE COLLECTOR LEAD FROM EMITTER AND BASE LEADS.

**FIGURE 15 – A UHF LOW NOISE TEST CIRCUIT, 450 MHz**

The effect of reducing the bandwidth can be seen by examining the following where tuning is shown in the input circuit:




$R_D$ = coil loss ($R_D$ = $Q_U X_L$)

$X_L$ = reactance of coil

$R_S'$ = optimum source resistance

The circuit bandwidth of this figure is described as:

$$\text{Bandwidth} \cong \frac{X_L f_o}{R'}$$

where:

$f_o$ = center frequency

$$R' = \frac{R_D R_S'}{R_D + R_S'} \cong R_S' .$$

Thus, it can be seen that reducing the bandwidth for a fixed value of $R_S'$ will require $X_L$ to also decrease. Unfortunately, reducing $X_L$ will also reduce $R_D$. Thus, decreasing the bandwidth of the input circuit will result in generally a higher noise figure, since the circuit loss increases.

An example of a UHF low noise test circuit is shown in Figure 15 in which noise figures as low as 2.1 dB are measured. 27,28.

The common emitter and common base configuration have approximately the same noise figure.[5] The final choice of which configuration to use is usually made by carefully considering other factors such as power gain, stability, and whether or not neutralization is acceptable.

## DESIGN CONSIDERATIONS FOR LOW FREQUENCY, LOW NOISE AMPLIFIERS

Excess noise (the predominant noise contributor at low frequencies) does not fit into a convenient noise model such as proposed by Nielsen. However, empirical investigation shows a similar dependence of noise figure on bias conditions and source impedance (see Figures 3 and 4). This dependence is of considerable importance in low frequency design and may dictate the type of device used (bipolar or field effect transistor). The major difficulty concerns transforming the system source impedance to the desired value (seen by the device) necessary for optimum noise figure. At high frequencies, transformation is readily accomplished with a simple tuned circuit. At low frequencies, however, transformation is limited to a transformer. Transformers are usually avoided if possible because of bandwidth, weight, noise pickup, loss and cost considerations. Consequently, rather than transforming the required source impedance (magnetic pick-up, etc.) to the desired resistance seen by the device, the device is usually selected and biased such that the required resistance seen by the device approximates the actual source resistance.

## BIBLIOGRAPHY


1. W.W. Harman and J.G. Terman, "Electronic Measurements," McGraw Hill Book Company, Inc., New York, 1952.
2. W.R. Bennett, "Electrical Noise," McGraw Hill Book Company.
3. "IRE Standards on Electron Tubes: Definition of Terms, 1957". Proc. IRE; Vol. 45, pp. 983-1010, July, 1957.
4. "Description of the Noise Performance of Amplifiers and Receiving Systems," Proceedings of the IEEE pp. 436-442, March, 1963.
5. E.G. Nielsen, "Behavior of Noise Figure in Junction Transistors," Proc. IRE, Vol. 45, p. 957, June, 1957.
6. A. van der Ziel, "Shot Noise in Junction Diodes and Transistors," Proc. IRE, Vol. 43, pp. 1639-1696, November, 1955.
7. A. van der Ziel, "Shot Noise in Transistors," Proc. IRE, Vol. 48, pp. 114-115, January, 1960.
8. H.A. Haus, et. al., "Representation of Noise in Linear Two-Ports," Proc. IRE, Vol. 48, pp. 69-74, January, 1960.
9. F.M. Gardner, "Optimum Noise Figure of Transistor Amplifiers," Proc. IRE, pp. 45-48, March, 1963.
10. W.A. Rheinfelder, "Design of Low-Noise Transistor Input Circuits." Hayden Book Company, Inc., New York, 1964.
11. J.J. Freeman, "Principles of Noise," John Wiley and Sons, Inc., 1958.
12. H.T. Friss, "Noise Figure of Radio Receivers," Proc. IRE, Vol. 32, No. 7, pp. 419-422, July, 1944.
13. W. Davenport and W. Root, "Random Signals and Noise," McGraw Hill Book Company, Inc., 1958.
14. L. Smullin and H. Haus, "Noise in Electron Devices," John Wiley and Sons, Inc., New York, 1959.
15. K. Sturley, "Radio Receiver Design," John Wiley and Sons, Inc., New York, 1953.
16. A. van der Ziel, "Noise," Prentice-Hall, Inc., 1954.
17. Hewlett Packard Application Note No. 57, Hewlett Packard, Palo Alto, California.
18. "Noise Figure Measurements," Airborne Instrument Laboratory, Deer Park, Long Island, New York.
19. "Topics in Noise Figure Measurements," Airborne Instrument Laboratory, Deer Park, Long Island, New York.
20. J. Pettit and M. McWharter, "Electronic Amplifier Circuits," McGraw Hill Book Company, Inc., New York, 1961.
21. J. Pierce, "Transistor Circuit Theory and Design," Charles E. Merrill Books, Inc., Columbus, Ohio, 1963.
22. J. Vasseur, "Properties and Applications of Transistors," The MacMillan Company, New York, 1964.
23. W. Austin, J. Dean, D. Griswold, and O. Hart, "T.V. Applications of MOS Transistors," RCA Proc. of NEC, Vol. 22, 1966, p. 1061.
24. E. McKean, F. Carlson, "Small-Signal RF Amplification of MOS Devices," RCA, Proc. of NEC, Vol. 22, p. 88, 1966.
25. G. Valley, H. Wallman, "Vacuum Tube Amplifier," p. 720, The McGraw Hill Book Company, Inc., New York, 1948.
26. R. Lane, "The Comparative Performance of FET and Bipolar Transistors at VHF," IEEE Journal of Solid-State Circuits, Vol. SC-1, No. 1, September, 1966.
27. R. Hejhall, "RF Small Signal Design Using 2-Port Parameters," Motorola Application Note AN-215A, Motorola Semiconductor Products Inc., Phoenix, Arizona.
28. "UHF Amplifier Design Using Data Sheet Design Curves," Motorola Application Note AN-419, Motorola Semiconductor Products Inc., Phoenix, Arizona.

# MATCHING NETWORK DESIGNS WITH COMPUTER SOLUTIONS

Prepared by:
**Frank Davis**

## INTRODUCTION

One of the problems facing the circuit design engineer is the design of high-frequency matching networks. Careful design of a network that will accomplish the required matching, harmonic attenuation, bandwidth, etc., and yield components of practical size can result in many hours spent with pencil and slide rule.

The design of matching networks for high frequency circuits involves an infinite number of possibilities, and a complete tabulation of possible network solutions would be virtually impossible. However, it is often necessary to design matching networks with a 50 + j 0 ohm impedance at one port. This, combined with a restricted range of impedance values to be matched, imposed by network and device limitations, makes practical a tabulation of some of the more commonly used networks. These design solutions are given in this report.

The network solutions included in this report have the limitation that one terminating impedance must be 50 + j 0 ohms. These networks are often used for matching in transistor RF power amplifier circuits that have a 50-ohm source or load. When the network does not have a 50-ohm termination at either port, the mathematical procedure given for each network in Appendix I can be used for the solution.

## COMPONENT CONSIDERATIONS

Four networks are presented in this report with solutions in the form of computer tabulations. Each network has its own limitations. Although the network configuration is normally up to the discretion of the design engineer, it is sometimes necessary to use one configuration in preference to another in order to obtain component values that are more realistic from a practical standpoint.

Component selection in the UHF and VHF frequency ranges becomes a major problem, and the network configuration to obtain realistic component values is of vital importance to the design engineer. Design calculations for matching networks can become completely meaningless unless the components for the network are measured at the operating frequency.

For example, a 100 pF silver mica capacitor that meets all specifications at 1 MHz can have as much capacitance as 300 pF at 100 MHz. At some frequency, the capacitor's series lead inductance will finally tune out the capacitance, thus leaving the capacitor net inductive.

Values of inductance in the low nanohenry range are also difficult to obtain, since the inductance of a one-inch straight piece of #20 solid tinned wire is approximately 20 nH.

Component tolerances have no meaning at VHF frequencies and above unless they are specified at the operating frequency. It cannot be over-emphasized that components must be measured at the operating frequency.

## NETWORK SOLUTIONS

The resistor and capacitor shown in the box labeled "device to be matched" represent the complex input or output impedance of a transistor. These complex impedances have been represented in series form in some cases and parallel form in others, depending on which form is most convenient for network calculation. The resultant impedance of the network, when terminated with 50 + j 0 ohms, must be equal to the conjugate of the impedance in the box. The computer tabulations provide this solution.

Network A (see Figure 1) is applicable only when the "device to be matched" has a series real part of less than 50 ohms. As we can see from the computer tabulation, as the series real part approaches 50 ohms, the reactance of $C_1$ approaches infinity. However, in RF power amplifiers, we normally find that the series real part of both the input and the output is less than 50 ohms, making this matching network applicable to most RF power amplifier stages. Where the terminating impedance is other than 50 ohms, the mathematical procedure for the network solution is given in Appendix I.

Network B (see Figure 2) is the Pi network widely used in vacuum tube transmitters. As is apparent from the computer tabulation, this network is often impractical for use where $R_1$ is small. For values of $R_1$ less than 50 ohms, the inductance of L becomes impractically small while the capacitance of both $C_1$ and $C_2$ become very large. Where the Pi network configuration must be used to match low values of impedance, a double Pi network, in which the Q of the first section is very low, can be utilized to yield practical components.

Network C has been solved in two forms (see Figure 3). Both of these networks have the limitation that $R_1$ must be less than 50 ohms. However, it must be stressed that this network configuration quite often yields the most practical components where low values of $R_1$ must be matched.

Network D (see Figure 4) is a "Tee" network. This network is useful for matching impedance less than or greater than 50 ohms. It has been observed in laboratory tests that this network configuration also yields very high collector efficiencies when used for output matching in transistor RF power amplifier stages.

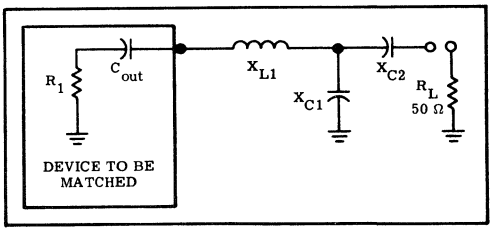



FIGURE 1 — NETWORK A

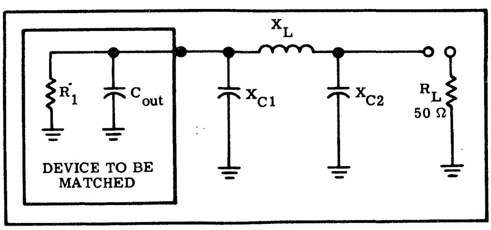



FIGURE 2 — NETWORK B

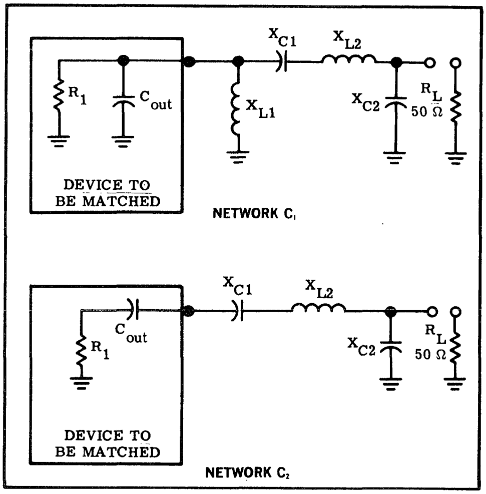



FIGURE 3

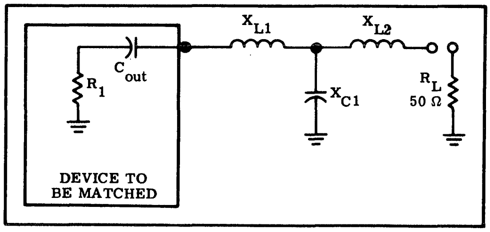



FIGURE 4 — NETWORK D

## SUMMARY

Four computer-solved networks have been presented. The mathematical procedure for the solution of each network has been given in Appendix I.* Although the networks have found major use in matching solid-state RF power amplifier stages, they are also applicable to any circuit where the individual network's limitations are fulfilled.

*For the derivation of the equations used, refer to Electronic Circuit Analysis, Volume 1, "Passive Networks," Philip Cutler.

## APPENDIX I

To convert a parallel resistance and reactance combination to series:

$$R_s = \frac{R_P}{1 + (R_P/X_P)^2}$$

$$X_s = R_s \frac{R_P}{X_P}$$

To convert a series resistance and reactance combination to parallel:

$$R_P = R_s[1 + (X_s/R_s)^2]$$

$$X_P = \frac{R_P}{X_s/R_s}$$

To solve network A:

1. Select a Q

$$X_{L1} = QR_1 + X_{C\,out}$$

$$X_{C2} = AR_L$$

$$X_{C1} = \frac{(B/A)(B/Q)}{(B/A)-(B/Q)} = \frac{B}{Q - A}$$

$$\text{where } A = \sqrt{\left[\frac{R_1(1+Q^2)}{R_L}\right] - 1}$$

$$B = R_1(1 + Q^2)$$

To solve network B:

1. Select a Q

$$X_{C1} = R_1/Q$$

$$X_{C2} = R_L\sqrt{\frac{R_1/R_L}{(Q^2+1)-(R_1/R_L)}}$$

$$X_L = \frac{QR_1 + (R_1R_L/X_{C2})}{Q^2 + 1}$$

To solve network $C_1$:

1. Select a Q

$$X_{L1} = X_{C\,out}$$

$$X_{C1} = QR_1$$

$$X_{C2} = R_L\sqrt{\frac{R_1}{R_L - R_1}}$$

$$X_{L2} = X_{C1} + \left(\frac{R_1R_L}{X_{C2}}\right)$$

To solve network $C_2$:

1. Select a Q

2. $L_1$ is not used in this network

$$X_{C1} = QR_1$$

$$X_{C2} = R_L\sqrt{\frac{R_1}{R_L - R_1}}$$

$$X_{L2} = X_{C1} + \left(\frac{R_1R_L}{X_{C2}}\right) + X_{C\,out}$$

To solve network D:

1. Select a Q

$$X_{L1} = (R_1Q) + X_{C\,out}$$

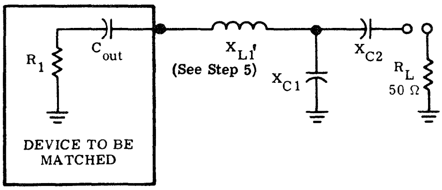
$$X_{L2} = R_LB$$

$$X_{C1} = \frac{(A/Q)(A/B)}{(A/Q)+(A/B)} = \frac{A}{Q + B}$$

$$\text{where } A = R_1(1 + Q^2)$$

$$B = \sqrt{\left(\frac{A}{R_L}\right) - 1}$$

## NETWORK A




TO DESIGN A NETWORK USING THE TABLES

1. Transform the parallel impedance of the device to be matched to series form ($R_1 + jX_{C_{out}}$).
2. Define Q, in column one, as $X_{L1}/R_1$.
3. Choose a Q.
4. For a Q, find the $R_s$ to be matched in the R column and read the reactive value of the components.
5. $X_{L1}'$ is equal to the quantity $X_{L1}$ obtained from the tables plus $|X_{C_{out}}|$.
6. This completes the network.

| Q | $X_{L1}$ | $X_{C1}$ | $X_{C2}$ | $R_1$ |
|---|---|---|---|---|
| 1 | 26 | 65 | 10 | 26 |
| 1 | 27 | 75.3 | 14.14 | 27 |
| 1 | 28 | 85.68 | 17.32 | 28 |
| 1 | 29 | 96.66 | 20 | 29 |
| 1 | 30 | 108.5 | 22.36 | 30 |
| 1 | 32 | 136 | 26.46 | 32 |
| 1 | 34 | 170 | 30 | 34 |
| 1 | 36 | 213.8 | 33.16 | 36 |
| 1 | 38 | 272.5 | 36.05 | 38 |
| 1 | 40 | 355 | 38.7 | 40 |
| 1 | 42 | 479 | 41.23 | 42 |
| 1 | 44 | 686.32 | 43.59 | 44 |
| 1 | 46 | 1102 | 45.83 | 46 |
| 1 | 48 | 2351 | 48 | 48 |
| 2 | 22 | 32.7 | 15.8 | 11 |
| 2 | 24 | 38.6 | 22.4 | 12 |
| 2 | 26 | 45 | 27.4 | 13 |
| 2 | 28 | 51.2 | 31.6 | 14 |
| 2 | 30 | 58 | 35.4 | 15 |
| 2 | 32 | 65.3 | 38.7 | 16 |
| 2 | 34 | 73.1 | 41.8 | 17 |
| 2 | 36 | 81.4 | 44.7 | 18 |
| 2 | 38 | 90.3 | 47.4 | 19 |
| 2 | 40 | 100 | 50 | 20 |
| 2 | 42 | 110.4 | 52.4 | 21 |
| 2 | 44 | 122 | 55 | 22 |
| 2 | 46 | 134 | 57 | 23 |
| 2 | 48 | 147 | 59 | 24 |
| 2 | 50 | 161 | 61 | 25 |
| 2 | 52 | 177 | 63 | 26 |
| 2 | 54 | 194 | 65 | 27 |
| 2 | 56 | 213 | 67 | 28 |
| 2 | 58 | 233 | 69 | 29 |
| 2 | 60 | 256 | 71 | 30 |
| 2 | 64 | 310 | 74 | 32 |
| 2 | 68 | 377 | 77 | 34 |
| 2 | 72 | 464 | 81 | 36 |
| 2 | 76 | 582 | 84 | 38 |
| 2 | 80 | 746 | 87 | 40 |
| 2 | 84 | 995 | 89 | 42 |
| 2 | 88 | 1409 | 92 | 44 |
| 2 | 92 | 2241 | 95 | 46 |
| 2 | 96 | 4739 | 97 | 48 |
| 3 | 18 | 23.5 | 22.3 | 6 |
| 3 | 21 | 29.6 | 31.6 | 7 |
| 3 | 24 | 35.9 | 38.7 | 8 |
| 3 | 27 | 42.7 | 44.7 | 9 |
| 3 | 30 | 50 | 50 | 10 |
| 3 | 33 | 57.8 | 54.8 | 11 |
| 3 | 36 | 66 | 59 | 12 |
| 3 | 39 | 75 | 63.2 | 13 |
| 3 | 42 | 84 | 67 | 14 |
| 3 | 45 | 95 | 71 | 15 |
| 3 | 48 | 105 | 74 | 16 |
| 3 | 51 | 117 | 77 | 17 |
| 3 | 54 | 130 | 81 | 18 |
| 3 | 57 | 143 | 84 | 19 |
| 3 | 60 | 158 | 87 | 20 |
| 3 | 63 | 173 | 89 | 21 |
| 3 | 66 | 190 | 92 | 22 |
| 3 | 69 | 209 | 95 | 23 |
| 3 | 72 | 228 | 97 | 24 |
| 3 | 75 | 250 | 100 | 25 |
| 3 | 78 | 274 | 102 | 26 |
| 3 | 81 | 299 | 105 | 27 |
| 3 | 84 | 327 | 107 | 28 |
| 3 | 87 | 358 | 110 | 29 |
| 3 | 90 | 393 | 112 | 30 |
| 3 | 96 | 473 | 116 | 32 |
| 3 | 102 | 575 | 120 | 34 |
| 3 | 108 | 706 | 124 | 36 |
| 3 | 114 | 882 | 128 | 38 |
| 3 | 120 | 1129 | 132 | 40 |
| 3 | 126 | 1502 | 136 | 42 |
| 3 | 132 | 2124 | 140 | 44 |
| 3 | 138 | 3372 | 143 | 46 |
| 3 | 144 | 7119 | 146 | 48 |
| 4 | 12 | 13.2 | 7.1 | 3 |
| 4 | 16 | 20 | 30 | 4 |
| 4 | 20 | 26.9 | 41.8 | 5 |
| 4 | 24 | 34.2 | 51 | 6 |
| 4 | 28 | 42.1 | 58.7 | 7 |
| 4 | 32 | 50.6 | 66 | 8 |
| 4 | 36 | 60 | 72 | 9 |
| 4 | 40 | 69 | 77 | 10 |
| 4 | 44 | 80 | 83 | 11 |
| 4 | 48 | 91 | 88 | 12 |
| 4 | 52 | 103 | 92 | 13 |
| 4 | 56 | 115 | 97 | 14 |
| 4 | 60 | 129 | 101 | 15 |
| 4 | 64 | 144 | 105 | 16 |
| 4 | 68 | 159 | 109 | 17 |
| 4 | 72 | 176 | 113 | 18 |
| 4 | 76 | 194 | 117 | 19 |
| 4 | 80 | 214 | 120 | 20 |
| 4 | 84 | 235 | 124 | 21 |
| 4 | 88 | 257 | 127 | 22 |
| 4 | 92 | 282 | 131 | 23 |
| 4 | 96 | 308 | 134 | 24 |
| 4 | 100 | 337 | 137 | 25 |
| 4 | 104 | 368 | 140 | 26 |
| 4 | 108 | 403 | 143 | 27 |
| 4 | 112 | 440 | 146 | 28 |
| 4 | 116 | 482 | 149 | 29 |
| 4 | 120 | 527 | 152 | 30 |
| 4 | 128 | 635 | 157 | 32 |
| 4 | 136 | 770 | 162 | 34 |
| 4 | 144 | 945 | 168 | 36 |
| 4 | 152 | 1180 | 173 | 38 |
| 4 | 160 | 1510 | 177 | 40 |
| 4 | 168 | 2007 | 182 | 42 |
| 4 | 176 | 2837 | 187 | 44 |
| 4 | 184 | 4500 | 191 | 46 |
| 4 | 192 | 9497 | 196 | 48 |
| 5 | 10 | 10.8 | 10 | 2 |
| 5 | 15 | 18.3 | 37.4 | 3 |
| 5 | 20 | 26.3 | 52 | 4 |
| 5 | 25 | 34.8 | 63.2 | 5 |
| 5 | 30 | 44 | 73 | 6 |
| 5 | 35 | 54 | 81 | 7 |
| 5 | 40 | 65 | 89 | 8 |
| 5 | 45 | 76 | 96 | 9 |
| 5 | 50 | 88 | 102 | 10 |
| 5 | 55 | 101 | 108 | 11 |
| 5 | 60 | 115 | 114 | 12 |
| 5 | 65 | 130 | 120 | 13 |
| 5 | 70 | 146 | 125 | 14 |
| 5 | 75 | 163 | 130 | 15 |
| 5 | 80 | 181 | 135 | 16 |
| 5 | 85 | 201 | 140 | 17 |
| 5 | 90 | 222 | 145 | 18 |
| 5 | 95 | 245 | 149 | 19 |
| 5 | 100 | 269 | 153 | 20 |
| 5 | 105 | 295 | 157 | 21 |
| 5 | 110 | 323 | 162 | 22 |
| 5 | 115 | 354 | 166 | 23 |
| 5 | 120 | 387 | 169 | 24 |
| 5 | 125 | 423 | 173 | 25 |
| 5 | 130 | 462 | 177 | 26 |
| 5 | 135 | 505 | 181 | 27 |
| 5 | 140 | 553 | 184 | 28 |
| 5 | 145 | 604 | 188 | 29 |
| 5 | 150 | 662 | 191 | 30 |
| 5 | 160 | 796 | 198 | 32 |
| 5 | 170 | 965 | 204 | 34 |
| 5 | 180 | 1184 | 210 | 36 |
| 5 | 190 | 1477 | 217 | 38 |
| 5 | 200 | 1890 | 222 | 40 |
| 5 | 210 | 2510 | 228 | 42 |
| 5 | 220 | 3548 | 234 | 44 |
| 5 | 230 | 5628 | 239 | 46 |
| 5 | 240 | 11874 | 245 | 48 |

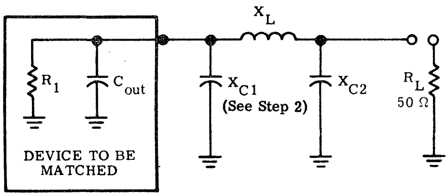
| Q | $X_{L1}$ | $X_{C1}$ | $X_{C2}$ | $R_1$ |
|---|---|---|---|---|
| 6 | 12 | 13.9 | 34.6 | 2 |
| 6 | 18 | 22.7 | 55.2 | 3 |
| 6 | 24 | 32.2 | 70 | 4 |
| 6 | 30 | 42.5 | 82 | 5 |
| 6 | 36 | 53.6 | 93 | 6 |
| 6 | 42 | 65.5 | 102 | 7 |
| 6 | 48 | 78 | 110 | 8 |
| 6 | 54 | 92 | 119 | 9 |
| 6 | 60 | 107 | 126 | 10 |
| 6 | 66 | 122 | 133 | 11 |
| 6 | 72 | 139 | 140 | 12 |
| 6 | 78 | 157 | 147 | 13 |
| 6 | 84 | 176 | 153 | 14 |
| 6 | 90 | 197 | 159 | 15 |
| 6 | 96 | 219 | 165 | 16 |
| 6 | 102 | 242 | 170 | 17 |
| 6 | 108 | 267 | 175 | 18 |
| 6 | 114 | 295 | 181 | 19 |
| 6 | 120 | 324 | 186 | 20 |
| 6 | 126 | 355 | 191 | 21 |
| 6 | 132 | 389 | 195 | 22 |
| 6 | 138 | 426 | 200 | 23 |
| 6 | 144 | 466 | 205 | 24 |
| 6 | 150 | 509 | 209 | 25 |
| 6 | 156 | 556 | 214 | 26 |
| 6 | 162 | 608 | 218 | 27 |
| 6 | 168 | 664 | 222 | 28 |
| 6 | 174 | 727 | 226 | 29 |
| 6 | 180 | 795 | 230 | 30 |
| 6 | 192 | 957 | 238 | 32 |
| 6 | 204 | 1160 | 246 | 34 |
| 6 | 216 | 1422 | 253 | 36 |
| 6 | 228 | 1775 | 260 | 38 |
| 6 | 240 | 2270 | 267 | 40 |
| 6 | 252 | 3015 | 274 | 42 |
| 6 | 264 | 4260 | 281 | 44 |
| 6 | 276 | 6755 | 287 | 46 |
| 6 | 288 | 14250 | 294 | 48 |
| 7 | 14 | 16.7 | 50 | 2 |
| 7 | 21 | 26.8 | 71 | 3 |
| 7 | 28 | 38 | 87 | 4 |
| 7 | 35 | 50 | 100 | 5 |
| 7 | 42 | 63 | 112 | 6 |
| 7 | 49 | 77 | 122 | 7 |
| 7 | 56 | 92 | 132 | 8 |
| 7 | 63 | 108 | 141 | 9 |
| 7 | 70 | 125 | 150 | 10 |
| 7 | 77 | 143 | 158 | 11 |
| 7 | 84 | 163 | 166 | 12 |
| 7 | 91 | 184 | 173 | 13 |
| 7 | 98 | 206 | 180 | 14 |
| 7 | 105 | 230 | 187 | 15 |
| 7 | 112 | 256 | 193 | 16 |
| 7 | 119 | 283 | 200 | 17 |
| 7 | 126 | 313 | 206 | 18 |
| 7 | 133 | 344 | 212 | 19 |
| 7 | 140 | 379 | 218 | 20 |
| 7 | 147 | 415 | 224 | 21 |
| 7 | 154 | 455 | 229 | 22 |
| 7 | 161 | 498 | 234 | 23 |
| 7 | 168 | 544 | 239 | 24 |
| 7 | 175 | 595 | 245 | 25 |
| 7 | 182 | 650 | 250 | 26 |

| Q | $X_{L1}$ | $X_{C1}$ | $X_{C2}$ | $R_1$ |
|---|---|---|---|---|
| 7 | 189 | 710 | 255 | 27 |
| 7 | 196 | 776 | 260 | 28 |
| 7 | 203 | 849 | 265 | 29 |
| 7 | 210 | 929 | 269 | 30 |
| 7 | 224 | 1117 | 278 | 32 |
| 7 | 238 | 1354 | 287 | 34 |
| 7 | 252 | 1661 | 296 | 36 |
| 7 | 266 | 2071 | 304 | 38 |
| 7 | 280 | 2649 | 312 | 40 |
| 7 | 294 | 3518 | 320 | 42 |
| 7 | 308 | 4971 | 328 | 44 |
| 7 | 322 | 7882 | 335 | 46 |
| 7 | 336 | 16626 | 343 | 48 |
| 8 | 8 | 8.7 | 27.4 | 1 |
| 8 | 16 | 19.3 | 63.2 | 2 |
| 8 | 24 | 31 | 85 | 3 |
| 8 | 32 | 43.6 | 102 | 4 |
| 8 | 40 | 57.4 | 117 | 5 |
| 8 | 48 | 72 | 130 | 6 |
| 8 | 56 | 88 | 142 | 7 |
| 8 | 64 | 105 | 153 | 8 |
| 8 | 72 | 124 | 164 | 9 |
| 8 | 80 | 143 | 173 | 10 |
| 8 | 88 | 164 | 182 | 11 |
| 8 | 96 | 187 | 191 | 12 |
| 8 | 104 | 211 | 199 | 13 |
| 8 | 112 | 236 | 207 | 14 |
| 8 | 120 | 264 | 215 | 15 |
| 8 | 128 | 293 | 222 | 16 |
| 8 | 136 | 324 | 230 | 17 |
| 8 | 144 | 358 | 237 | 18 |
| 8 | 152 | 394 | 243 | 19 |
| 8 | 160 | 433 | 250 | 20 |
| 8 | 168 | 475 | 256 | 21 |
| 8 | 176 | 521 | 263 | 22 |
| 8 | 184 | 570 | 269 | 23 |
| 8 | 192 | 623 | 275 | 24 |
| 8 | 200 | 681 | 281 | 25 |
| 8 | 208 | 744 | 286 | 26 |
| 8 | 216 | 812 | 292 | 27 |
| 8 | 224 | 888 | 297 | 28 |
| 8 | 232 | 971 | 303 | 29 |
| 8 | 240 | 1062 | 308 | 30 |
| 8 | 256 | 1277 | 318 | 32 |
| 8 | 272 | 1548 | 329 | 34 |
| 8 | 288 | 1899 | 338 | 36 |
| 8 | 304 | 2368 | 348 | 38 |
| 8 | 320 | 3028 | 357 | 40 |
| 8 | 336 | 4022 | 366 | 42 |
| 8 | 352 | 5682 | 375 | 44 |
| 8 | 368 | 9009 | 383 | 46 |
| 9 | 9 | 10 | 40 | 1 |
| 9 | 18 | 21.9 | 76 | 2 |
| 9 | 27 | 35 | 99 | 3 |
| 9 | 36 | 49.4 | 118 | 4 |
| 9 | 45 | 65 | 134 | 5 |
| 9 | 54 | 82 | 149 | 6 |
| 9 | 63 | 100 | 162 | 7 |
| 9 | 72 | 119 | 174 | 8 |
| 9 | 81 | 139 | 185 | 9 |
| 9 | 90 | 162 | 196 | 10 |
| 9 | 99 | 185 | 206 | 11 |

| Q | $X_{L1}$ | $X_{C1}$ | $X_{C2}$ | $R_1$ |
|---|---|---|---|---|
| 9 | 108 | 210 | 216 | 12 |
| 9 | 117 | 237 | 225 | 13 |
| 9 | 126 | 266 | 234 | 14 |
| 9 | 135 | 297 | 243 | 15 |
| 9 | 144 | 330 | 251 | 16 |
| 9 | 153 | 365 | 259 | 17 |
| 9 | 162 | 403 | 267 | 18 |
| 9 | 171 | 444 | 275 | 19 |
| 9 | 180 | 488 | 282 | 20 |
| 9 | 189 | 535 | 289 | 21 |
| 9 | 198 | 586 | 296 | 22 |
| 9 | 207 | 641 | 303 | 23 |
| 9 | 216 | 701 | 310 | 24 |
| 9 | 225 | 766 | 316 | 25 |
| 9 | 234 | 837 | 323 | 26 |
| 9 | 243 | 914 | 329 | 27 |
| 9 | 252 | 999 | 335 | 28 |
| 9 | 261 | 1092 | 341 | 29 |
| 9 | 270 | 1196 | 347 | 30 |
| 9 | 288 | 1438 | 359 | 32 |
| 9 | 306 | 1743 | 370 | 34 |
| 9 | 324 | 2137 | 381 | 36 |
| 9 | 342 | 2665 | 391 | 38 |
| 9 | 360 | 3407 | 402 | 40 |
| 9 | 378 | 4525 | 412 | 42 |
| 9 | 396 | 6393 | 422 | 44 |
| 10 | 10 | 11.2 | 50.5 | 1 |
| 10 | 20 | 24.5 | 87 | 2 |
| 10 | 30 | 39 | 112 | 3 |
| 10 | 40 | 55 | 133 | 4 |
| 10 | 50 | 72 | 151 | 5 |
| 10 | 60 | 91 | 167 | 6 |
| 10 | 70 | 111 | 181 | 7 |
| 10 | 80 | 132 | 195 | 8 |
| 10 | 90 | 155 | 207 | 9 |
| 10 | 100 | 180 | 219 | 10 |
| 10 | 110 | 206 | 230 | 11 |
| 10 | 120 | 234 | 241 | 12 |
| 10 | 130 | 264 | 251 | 13 |
| 10 | 140 | 296 | 261 | 14 |
| 10 | 150 | 330 | 271 | 15 |
| 10 | 160 | 367 | 280 | 16 |
| 10 | 170 | 406 | 289 | 17 |
| 10 | 180 | 448 | 297 | 18 |
| 10 | 190 | 494 | 306 | 19 |
| 10 | 200 | 543 | 314 | 20 |
| 10 | 210 | 595 | 322 | 21 |
| 10 | 220 | 652 | 330 | 22 |
| 10 | 230 | 713 | 337 | 23 |
| 10 | 240 | 780 | 345 | 24 |
| 10 | 250 | 852 | 352 | 25 |
| 10 | 260 | 930 | 359 | 26 |
| 10 | 270 | 1016 | 366 | 27 |
| 10 | 280 | 1111 | 373 | 28 |
| 10 | 290 | 1214 | 379 | 29 |
| 10 | 300 | 1329 | 383 | 30 |
| 10 | 320 | 1598 | 399 | 32 |
| 10 | 340 | 1937 | 411 | 34 |
| 10 | 360 | 2375 | 423 | 36 |
| 10 | 380 | 2961 | 435 | 38 |
| 10 | 400 | 3787 | 446 | 40 |
| 10 | 420 | 5029 | 458 | 42 |
| 10 | 440 | 7104 | 469 | 44 |

## NETWORK B

The following is a computer solution for the Pi network when $R_L$ equals 50 ohms.




TO DESIGN A NETWORK USING THE TABLES

1. Define Q, in column one, as $R_1/X_{C1}$.
2. $C_1$ actual is equal to $C_1$ – parallel $C_{out}$ of device to be matched.
3. This completes the network.

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 1 | 1 | 5.03 | 5.47 | 1 |
| 1 | 2 | 7.14 | 8 | 2 |
| 1 | 3 | 8.79 | 10.03 | 3 |
| 1 | 4 | 10.21 | 11.8 | 4 |
| 1 | 5 | 11.47 | 13.4 | 5 |
| 1 | 10 | 16.67 | 20 | 10 |
| 1 | 15 | 21 | 25.35 | 15 |
| 1 | 20 | 25 | 30 | 20 |
| 1 | 25 | 28.87 | 34.15 | 25 |
| 1 | 30 | 32.73 | 37.91 | 30 |
| 1 | 35 | 36.69 | 41.35 | 35 |
| 1 | 40 | 40.82 | 44.49 | 40 |
| 1 | 45 | 45.23 | 47.37 | 45 |
| 1 | 50 | 50 | 50 | 50 |
| 1 | 55 | 55.28 | 52.37 | 55 |
| 1 | 60 | 61.24 | 54.49 | 60 |
| 1 | 65 | 68.14 | 56.35 | 65 |
| 1 | 70 | 76.38 | 57.91 | 70 |
| 1 | 75 | 86.6 | 59.15 | 75 |
| 1 | 80 | 100 | 60 | 80 |
| 1 | 85 | 119.02 | 60.35 | 85 |
| 1 | 90 | 150 | 60 | 90 |
| 2 | 0.5 | 3.17 | 3.56 | 1 |
| 2 | 1 | 4.49 | 5.25 | 2 |
| 2 | 1.5 | 5.51 | 6.64 | 3 |
| 2 | 2 | 6.38 | 7.87 | 4 |
| 2 | 2.5 | 7.14 | 9 | 5 |
| 2 | 5 | 10.21 | 13.8 | 10 |
| 2 | 7.5 | 12.63 | 17.87 | 15 |
| 2 | 10 | 14.74 | 21.56 | 20 |
| 2 | 12.5 | 16.67 | 25 | 25 |
| 2 | 15 | 18.46 | 28.25 | 30 |
| 2 | 17.5 | 20.17 | 31.35 | 35 |
| 2 | 20 | 21.82 | 34.33 | 40 |
| 2 | 22.5 | 23.43 | 37.21 | 45 |
| 2 | 25 | 25 | 40 | 50 |
| 2 | 27.5 | 26.55 | 42.71 | 55 |
| 2 | 30 | 28.1 | 45.35 | 60 |
| 2 | 32.5 | 29.64 | 47.93 | 65 |
| 2 | 35 | 31.18 | 50.45 | 70 |
| 2 | 37.5 | 32.73 | 52.91 | 75 |
| 2 | 40 | 34.3 | 55.32 | 80 |
| 2 | 42.5 | 35.89 | 57.69 | 85 |
| 2 | 45 | 37.5 | 60 | 90 |
| 2 | 47.5 | 39.14 | 62.27 | 95 |
| 2 | 50 | 40.82 | 64.49 | 100 |
| 2 | 62.5 | 50 | 75 | 125 |
| 2 | 75 | 61.24 | 84.49 | 150 |
| 2 | 87.5 | 76.38 | 92.91 | 175 |
| 2 | 100 | 100 | 100 | 200 |
| 2 | 112.5 | 150 | 105 | 225 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 3 | 0.33 | 2.24 | 2.53 | 1 |
| 3 | 0.67 | 3.17 | 3.76 | 2 |
| 3 | 1 | 3.88 | 4.76 | 3 |
| 3 | 1.33 | 4.49 | 5.65 | 4 |
| 3 | 1.67 | 5.03 | 6.47 | 5 |
| 3 | 3.33 | 7.14 | 10 | 10 |
| 3 | 5 | 8.79 | 13.03 | 15 |
| 3 | 6.67 | 10.21 | 15.8 | 20 |
| 3 | 8.33 | 11.47 | 18.4 | 25 |
| 3 | 10 | 12.63 | 20.87 | 30 |
| 3 | 11.67 | 13.72 | 23.26 | 35 |
| 3 | 13.33 | 14.74 | 25.56 | 40 |
| 3 | 15 | 15.72 | 27.81 | 45 |
| 3 | 16.67 | 16.67 | 30 | 50 |
| 3 | 18.33 | 17.58 | 32.14 | 55 |
| 3 | 20 | 18.46 | 34.25 | 60 |
| 3 | 21.67 | 19.33 | 36.32 | 65 |
| 3 | 23.33 | 20.17 | 38.35 | 70 |
| 3 | 25 | 21 | 40.35 | 75 |
| 3 | 26.67 | 21.82 | 42.33 | 80 |
| 3 | 28.33 | 22.63 | 44.28 | 85 |
| 3 | 30 | 23.43 | 46.21 | 90 |
| 3 | 31.67 | 24.22 | 48.12 | 95 |
| 3 | 33.33 | 25 | 50 | 100 |
| 3 | 41.67 | 28.87 | 59.12 | 125 |
| 3 | 50 | 32.73 | 67.91 | 150 |
| 3 | 58.33 | 36.69 | 76.35 | 175 |
| 3 | 66.67 | 40.82 | 84.49 | 200 |
| 3 | 75 | 45.23 | 92.37 | 225 |
| 3 | 83.33 | 50 | 100 | 250 |
| 4 | 6.25 | 8.7 | 14.33 | 25 |
| 4 | 12.5 | 12.5 | 23.53 | 50 |
| 4 | 18.75 | 15.55 | 31.83 | 75 |
| 4 | 25 | 18.26 | 39.64 | 100 |
| 4 | 31.25 | 20.76 | 47.12 | 125 |
| 4 | 37.5 | 23.15 | 54.36 | 150 |
| 4 | 43.75 | 25.46 | 61.39 | 175 |
| 4 | 50 | 27.74 | 68.27 | 200 |
| 4 | 56.25 | 30 | 75 | 225 |
| 4 | 62.5 | 32.27 | 81.61 | 250 |
| 4 | 75 | 36.93 | 94.48 | 300 |
| 4 | 100 | 47.14 | 119.07 | 400 |
| 4 | 125 | 59.76 | 142.25 | 500 |
| 4 | 150 | 77.46 | 163.96 | 600 |
| 4 | 175 | 108.01 | 183.77 | 700 |
| 4 | 200 | 200 | 200 | 800 |
| 5 | 0.2 | 1.39 | 1.58 | 1 |
| 5 | 5 | 7 | 11.67 | 25 |
| 5 | 10 | 10 | 19.23 | 50 |
| 5 | 15 | 12.37 | 26.08 | 75 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 5 | 20 | 14.43 | 32.55 | 100 |
| 5 | 25 | 16.31 | 38.78 | 125 |
| 5 | 30 | 18.06 | 44.82 | 150 |
| 5 | 35 | 19.72 | 50.72 | 175 |
| 5 | 40 | 21.32 | 56.5 | 200 |
| 5 | 45 | 22.87 | 62.18 | 225 |
| 5 | 50 | 24.4 | 67.78 | 250 |
| 5 | 60 | 27.39 | 78.76 | 300 |
| 5 | 80 | 33.33 | 100 | 400 |
| 5 | 100 | 39.53 | 120.48 | 500 |
| 5 | 120 | 46.29 | 140.31 | 600 |
| 5 | 140 | 54.01 | 159.54 | 700 |
| 5 | 160 | 63.25 | 178.17 | 800 |
| 5 | 180 | 75 | 196.15 | 900 |
| 5 | 200 | 91.29 | 213.37 | 1000 |
| 5 | 220 | 117.26 | 229.58 | 1100 |
| 5 | 240 | 173.21 | 244.09 | 1200 |
| 6 | 0.17 | 1.16 | 1.32 | 1 |
| 6 | 4.17 | 5.85 | 9.83 | 25 |
| 6 | 8.33 | 8.33 | 16.22 | 50 |
| 6 | 12.5 | 10.28 | 22.02 | 75 |
| 6 | 16.67 | 11.95 | 27.52 | 100 |
| 6 | 20.83 | 13.46 | 32.82 | 125 |
| 6 | 25 | 14.85 | 37.97 | 150 |
| 6 | 29.17 | 16.16 | 43.01 | 175 |
| 6 | 33.33 | 17.41 | 47.96 | 200 |
| 6 | 37.5 | 18.61 | 52.83 | 225 |
| 6 | 41.67 | 19.76 | 57.63 | 250 |
| 6 | 50 | 22 | 67.08 | 300 |
| 6 | 66.67 | 26.26 | 85.45 | 400 |
| 6 | 83.33 | 30.43 | 103.29 | 500 |
| 6 | 100 | 34.64 | 120.7 | 600 |
| 6 | 116.67 | 39.01 | 137.76 | 700 |
| 6 | 133.33 | 43.64 | 154.5 | 800 |
| 6 | 150 | 48.67 | 170.94 | 900 |
| 6 | 166.67 | 54.23 | 187.08 | 1000 |
| 6 | 183.33 | 60.55 | 202.93 | 1100 |
| 6 | 200 | 67.94 | 218.46 | 1200 |
| 6 | 216.67 | 76.87 | 233.66 | 1300 |
| 6 | 233.33 | 88.19 | 248.48 | 1400 |
| 6 | 250 | 103.51 | 262.83 | 1500 |
| 6 | 266.67 | 126.49 | 276.55 | 1600 |
| 6 | 283.33 | 168.33 | 289.32 | 1700 |
| 6 | 300 | 300 | 300 | 1800 |
| 7 | 0.14 | 1 | 1.14 | 1 |
| 7 | 3.57 | 5.03 | 8.47 | 25 |
| 7 | 7.14 | 7.14 | 14 | 50 |
| 7 | 10.71 | 8.79 | 19.03 | 75 |
| 7 | 14.29 | 10.21 | 23.8 | 100 |
| 7 | 17.86 | 11.47 | 28.4 | 125 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 7 | 21.43 | 12.63 | 32.87 | 150 |
| 7 | 25 | 13.72 | 37.26 | 175 |
| 7 | 28.57 | 14.74 | 41.56 | 200 |
| 7 | 32.14 | 15.72 | 45.81 | 225 |
| 7 | 35.71 | 16.67 | 50 | 250 |
| 7 | 42.86 | 18.46 | 58.25 | 300 |
| 7 | 57.14 | 21.82 | 74.33 | 400 |
| 7 | 71.43 | 25 | 90 | 500 |
| 7 | 85.71 | 28.1 | 105.35 | 600 |
| 7 | 100 | 31.18 | 120.45 | 700 |
| 7 | 114.29 | 34.3 | 135.32 | 800 |
| 7 | 128.57 | 37.5 | 150 | 900 |
| 7 | 142.86 | 40.82 | 164.49 | 1000 |
| 7 | 171.43 | 48.04 | 192.98 | 1200 |
| 7 | 200 | 56.41 | 220.82 | 1400 |
| 7 | 228.57 | 66.67 | 248 | 1600 |
| 7 | 257.14 | 80.18 | 274.45 | 1800 |
| 7 | 285.71 | 100 | 300 | 2000 |
| 7 | 314.29 | 135.4 | 324.25 | 2200 |
| 7 | 342.86 | 244.95 | 345.8 | 2400 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 8 | 0.13 | 0.88 | 1 | 1 |
| 8 | 3.13 | 4.4 | 7.45 | 25 |
| 8 | 6.25 | 6.25 | 12.31 | 50 |
| 8 | 9.38 | 7.68 | 16.74 | 75 |
| 8 | 12.5 | 8.91 | 20.94 | 100 |
| 8 | 15.63 | 10 | 25 | 125 |
| 8 | 18.75 | 11 | 28.95 | 150 |
| 8 | 21.88 | 11.93 | 32.82 | 175 |
| 8 | 25 | 12.8 | 36.63 | 200 |
| 8 | 28.13 | 13.64 | 40.38 | 225 |
| 8 | 31.25 | 14.43 | 44.09 | 250 |
| 8 | 37.5 | 15.94 | 51.4 | 300 |
| 8 | 50 | 18.73 | 65.66 | 400 |
| 8 | 62.5 | 21.32 | 79.58 | 500 |
| 8 | 75 | 23.79 | 93.25 | 600 |
| 8 | 87.5 | 26.2 | 106.71 | 700 |
| 8 | 100 | 28.57 | 120 | 800 |
| 8 | 112.5 | 30.94 | 133.14 | 900 |
| 8 | 125 | 33.33 | 146.15 | 1000 |
| 8 | 150 | 38.25 | 171.82 | 1200 |
| 8 | 175 | 43.5 | 197.07 | 1400 |
| 8 | 200 | 49.24 | 221.92 | 1600 |
| 8 | 225 | 55.71 | 246.39 | 1800 |
| 8 | 250 | 63.25 | 270.48 | 2000 |
| 8 | 275 | 72.37 | 294.15 | 2200 |
| 8 | 300 | 84.02 | 317.36 | 2400 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 9 | 8.33 | 6.83 | 14.93 | 75 |
| 9 | 11.11 | 7.91 | 18.69 | 100 |
| 9 | 13.89 | 8.87 | 22.32 | 125 |
| 9 | 16.67 | 9.74 | 25.85 | 150 |
| 9 | 19.44 | 10.56 | 29.31 | 175 |
| 9 | 22.22 | 11.32 | 32.72 | 200 |
| 9 | 25 | 12.05 | 36.08 | 225 |
| 9 | 27.78 | 12.74 | 39.4 | 250 |
| 9 | 33.33 | 14.05 | 45.95 | 300 |
| 9 | 44.44 | 16.44 | 58.74 | 400 |
| 9 | 55.56 | 18.63 | 71.24 | 500 |
| 9 | 66.67 | 20.7 | 83.53 | 600 |
| 9 | 77.78 | 22.69 | 95.64 | 700 |
| 9 | 88.89 | 24.62 | 107.62 | 800 |
| 9 | 100 | 26.52 | 119.48 | 900 |
| 9 | 111.11 | 28.4 | 131.23 | 1000 |
| 9 | 133.33 | 32.16 | 154.46 | 1200 |
| 9 | 155.56 | 36 | 177.37 | 1400 |
| 9 | 177.78 | 40 | 200 | 1600 |
| 9 | 200 | 44.23 | 222.37 | 1800 |
| 9 | 222.22 | 48.8 | 244.5 | 2000 |
| 9 | 244.44 | 53.8 | 266.4 | 2200 |
| 9 | 266.67 | 59.41 | 288.05 | 2400 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 10 | 0.1 | 0.7 | 0.8 | 1 |
| 10 | 5 | 5 | 9.9 | 50 |
| 10 | 10 | 7.11 | 16.87 | 100 |
| 10 | 15 | 8.75 | 23.34 | 150 |
| 10 | 20 | 10.15 | 29.55 | 200 |
| 10 | 25 | 11.41 | 35.6 | 250 |
| 10 | 30 | 12.57 | 41.52 | 300 |
| 10 | 40 | 14.66 | 53.11 | 400 |
| 10 | 50 | 16.57 | 64.44 | 500 |
| 10 | 60 | 18.36 | 75.58 | 600 |
| 10 | 70 | 20.06 | 86.58 | 700 |
| 10 | 80 | 21.69 | 97.46 | 800 |
| 10 | 90 | 23.28 | 108.24 | 900 |
| 10 | 100 | 24.85 | 118.94 | 1000 |
| 10 | 120 | 27.91 | 140.09 | 1200 |
| 10 | 140 | 30.97 | 161 | 1400 |
| 10 | 160 | 34.05 | 181.68 | 1600 |
| 10 | 180 | 37.21 | 202.17 | 1800 |
| 10 | 200 | 40.49 | 222.47 | 2000 |
| 10 | 220 | 43.93 | 242.61 | 2200 |
| 10 | 240 | 47.58 | 262.59 | 2400 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 12 | 25 | 10.39 | 34.79 | 300 |
| 12 | 33.33 | 12.08 | 44.52 | 400 |
| 12 | 41.67 | 13.61 | 54.05 | 500 |
| 12 | 50 | 15.02 | 63.43 | 600 |
| 12 | 58.33 | 16.35 | 72.7 | 700 |
| 12 | 66.67 | 17.61 | 81.87 | 800 |
| 12 | 75 | 18.82 | 90.97 | 900 |
| 12 | 83.33 | 20 | 100 | 1000 |
| 12 | 100 | 22.27 | 117.89 | 1200 |
| 12 | 116.67 | 24.46 | 135.6 | 1400 |
| 12 | 133.33 | 26.61 | 153.15 | 1600 |
| 12 | 150 | 28.73 | 170.57 | 1800 |
| 12 | 166.67 | 30.86 | 187.86 | 2000 |
| 12 | 183.33 | 33 | 205.06 | 2200 |
| 12 | 200 | 35.17 | 222.15 | 2400 |
| 12 | 216.67 | 37.39 | 239.16 | 2600 |
| 12 | 233.33 | 39.66 | 256.07 | 2800 |
| 12 | 250 | 42.01 | 272.9 | 3000 |
| 12 | 291.67 | 48.3 | 314.64 | 3500 |
| 12 | 333.33 | 55.47 | 355.9 | 4000 |
| 12 | 375 | 63.96 | 396.67 | 4500 |
| 12 | 416.67 | 74.54 | 436.92 | 5000 |
| 12 | 458.33 | 88.64 | 476.57 | 5500 |
| 12 | 500 | 109.54 | 515.44 | 6000 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 14 | 21.43 | 8.86 | 29.91 | 300 |
| 14 | 28.57 | 10.29 | 38.3 | 400 |
| 14 | 35.71 | 11.56 | 46.51 | 500 |
| 14 | 42.86 | 12.73 | 54.6 | 600 |
| 14 | 50 | 13.83 | 62.59 | 700 |
| 14 | 57.14 | 14.87 | 70.51 | 800 |
| 14 | 64.29 | 15.86 | 78.37 | 900 |
| 14 | 71.43 | 16.81 | 86.17 | 1000 |
| 14 | 85.71 | 18.62 | 101.63 | 1200 |
| 14 | 100 | 20.35 | 116.95 | 1400 |
| 14 | 114.29 | 22.02 | 132.15 | 1600 |
| 14 | 128.57 | 23.64 | 147.24 | 1800 |
| 14 | 142.86 | 25.24 | 162.25 | 2000 |
| 14 | 157.14 | 26.81 | 177.17 | 2200 |
| 14 | 171.43 | 28.38 | 192.02 | 2400 |
| 14 | 185.71 | 29.94 | 206.81 | 2600 |
| 14 | 200 | 31.51 | 221.54 | 2800 |
| 14 | 214.29 | 33.09 | 236.21 | 3000 |
| 14 | 250 | 37.12 | 272.66 | 3500 |
| 14 | 285.71 | 41.34 | 308.82 | 4000 |
| 14 | 321.43 | 45.86 | 344.7 | 4500 |
| 14 | 357.14 | 50.77 | 380.33 | 5000 |
| 14 | 392.86 | 56.22 | 415.69 | 5500 |
| 14 | 428.57 | 62.42 | 450.79 | 6000 |

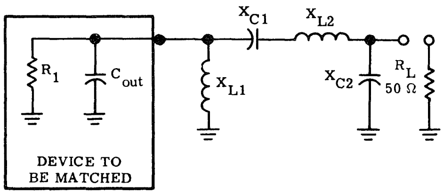
| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 16 | 18.75 | 7.73 | 26.23 | 300 |
| 16 | 25 | 8.96 | 33.59 | 400 |
| 16 | 31.25 | 10.06 | 40.8 | 500 |
| 16 | 37.5 | 11.07 | 47.9 | 600 |
| 16 | 43.75 | 12 | 54.93 | 700 |
| 16 | 50 | 12.88 | 61.89 | 800 |
| 16 | 56.25 | 13.72 | 68.79 | 900 |
| 16 | 62.5 | 14.52 | 75.65 | 1000 |
| 16 | 75 | 16.05 | 89.26 | 1200 |
| 16 | 87.5 | 17.48 | 102.74 | 1400 |
| 16 | 100 | 18.86 | 116.12 | 1600 |
| 16 | 112.5 | 20.18 | 129.42 | 1800 |
| 16 | 125 | 21.47 | 142.64 | 2000 |
| 16 | 137.5 | 22.73 | 155.8 | 2200 |
| 16 | 150 | 23.96 | 168.9 | 2400 |
| 16 | 162.5 | 25.18 | 181.95 | 2600 |
| 16 | 175 | 26.39 | 194.96 | 2800 |
| 16 | 187.5 | 27.59 | 207.92 | 3000 |
| 16 | 218.75 | 30.59 | 240.16 | 3500 |
| 16 | 250 | 33.61 | 272.18 | 4000 |
| 16 | 281.25 | 36.71 | 304.01 | 4500 |
| 16 | 312.5 | 39.9 | 335.66 | 5000 |
| 16 | 343.75 | 43.25 | 367.15 | 5500 |
| 16 | 375 | 46.8 | 398.49 | 6000 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 18 | 16.67 | 6.86 | 23.35 | 300 |
| 18 | 22.22 | 7.94 | 29.9 | 400 |
| 18 | 27.78 | 8.91 | 36.33 | 500 |
| 18 | 33.33 | 9.79 | 42.66 | 600 |
| 18 | 38.89 | 10.61 | 48.92 | 700 |
| 18 | 44.44 | 11.38 | 55.13 | 800 |
| 18 | 50 | 12.11 | 61.28 | 900 |
| 18 | 55.56 | 12.8 | 67.4 | 1000 |
| 18 | 66.67 | 14.12 | 79.54 | 1200 |
| 18 | 77.78 | 15.35 | 91.57 | 1400 |
| 18 | 88.89 | 16.52 | 103.51 | 1600 |
| 18 | 100 | 17.65 | 115.38 | 1800 |
| 18 | 111.11 | 18.73 | 127.2 | 2000 |
| 18 | 122.22 | 19.79 | 138.95 | 2200 |
| 18 | 133.33 | 20.81 | 150.66 | 2400 |
| 18 | 144.44 | 21.82 | 162.33 | 2600 |
| 18 | 155.56 | 22.81 | 173.96 | 2800 |
| 18 | 166.67 | 23.79 | 185.55 | 3000 |
| 18 | 194.44 | 26.2 | 214.4 | 3500 |
| 18 | 222.22 | 28.57 | 243.08 | 4000 |
| 18 | 250 | 30.94 | 271.6 | 4500 |
| 18 | 277.78 | 33.33 | 300 | 5000 |
| 18 | 305.56 | 35.76 | 328.27 | 5500 |
| 18 | 333.33 | 38.25 | 356.44 | 6000 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_L$ | $R_1$ |
|---|---|---|---|---|
| 20 | 15 | 6.16 | 21.03 | 300 |
| 20 | 20 | 7.13 | 26.94 | 400 |
| 20 | 25 | 8 | 32.73 | 500 |
| 20 | 30 | 8.78 | 38.44 | 600 |
| 20 | 35 | 9.51 | 44.09 | 700 |
| 20 | 40 | 10.19 | 49.69 | 800 |
| 20 | 45 | 10.84 | 55.24 | 900 |
| 20 | 50 | 11.46 | 60.76 | 1000 |
| 20 | 60 | 12.62 | 71.71 | 1200 |
| 20 | 70 | 13.7 | 82.57 | 1400 |
| 20 | 80 | 14.72 | 93.35 | 1600 |
| 20 | 90 | 15.7 | 104.07 | 1800 |
| 20 | 100 | 16.64 | 114.73 | 2000 |
| 20 | 110 | 17.55 | 125.35 | 2200 |
| 20 | 120 | 18.44 | 135.93 | 2400 |
| 20 | 130 | 19.3 | 146.47 | 2600 |
| 20 | 140 | 20.14 | 156.98 | 2800 |
| 20 | 150 | 20.97 | 167.46 | 3000 |
| 20 | 175 | 22.99 | 193.54 | 3500 |
| 20 | 200 | 24.96 | 219.48 | 4000 |
| 20 | 225 | 26.9 | 245.3 | 4500 |
| 20 | 250 | 28.82 | 271.01 | 5000 |
| 20 | 275 | 30.74 | 296.62 | 5500 |
| 20 | 300 | 32.67 | 322.15 | 6000 |

## NETWORK $C_1$

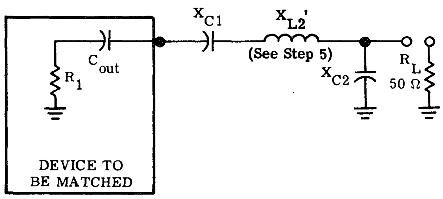
The following is a computer solution for an RF matching network. This computer solution is applicable for two forms of matching networks.




TO DESIGN A NETWORK USING THE TABLES

1. $X_{L1} = X_{C\,out}$.
2. Define Q, in column one, as $X_{C1}/R_1$.
3. All network values can now be read from the charts in terms of reactance.
4. This completes network $C_1$.

## NETWORK $C_2$




TO DESIGN A NETWORK USING THE TABLES

1. $L_1$ is not used in this network.
2. Transform the impedance of the device to be matched to series form ($R_1 + jX_{C\,out}$).
3. Define Q, in column one, as $X_{C1}/R_1$.
4. For a desired Q, find the $R_s$ to be matched in the $R_1$ column and read the reactive value of the components.
5. $X_{L2}'$ is equal to the quantity $X_{L2}$ obtained from the tables plus $|X_{C_{out}}|$.
6. This completes network $C_2$.

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 1 | 1 | 7.14 | 8 | 1 |
| 1 | 2 | 10.21 | 11.8 | 2 |
| 1 | 3 | 12.63 | 14.87 | 3 |
| 1 | 4 | 14.74 | 17.56 | 4 |
| 1 | 5 | 16.67 | 20 | 5 |
| 1 | 6 | 18.46 | 22.25 | 6 |
| 1 | 7 | 20.17 | 24.35 | 7 |
| 1 | 8 | 21.82 | 26.33 | 8 |
| 1 | 9 | 23.43 | 28.21 | 9 |
| 1 | 10 | 25 | 30 | 10 |
| 1 | 11 | 26.55 | 31.81 | 11 |
| 1 | 12 | 28.1 | 33.35 | 12 |
| 1 | 13 | 29.64 | 34.93 | 13 |
| 1 | 14 | 31.13 | 36.45 | 14 |
| 1 | 15 | 32.73 | 37.91 | 15 |
| 1 | 16 | 34.3 | 39.32 | 16 |
| 1 | 17 | 35.89 | 40.69 | 17 |
| 1 | 18 | 37.5 | 42 | 18 |
| 1 | 19 | 39.14 | 43.27 | 19 |
| 1 | 20 | 40.82 | 44.49 | 20 |
| 1 | 21 | 42.55 | 45.68 | 21 |
| 1 | 22 | 44.32 | 46.82 | 22 |
| 1 | 23 | 46.15 | 47.92 | 23 |
| 1 | 24 | 48.04 | 48.98 | 24 |
| 1 | 25 | 50 | 50 | 25 |
| 1 | 26 | 52.04 | 50.98 | 26 |
| 1 | 27 | 54.17 | 51.92 | 27 |
| 1 | 28 | 56.41 | 52.82 | 28 |
| 1 | 29 | 58.76 | 53.68 | 29 |
| 1 | 30 | 61.24 | 54.49 | 30 |
| 1 | 32 | 66.67 | 56 | 32 |
| 1 | 34 | 72.89 | 57.32 | 34 |
| 1 | 36 | 80.18 | 58.45 | 36 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 1 | 38 | 88.98 | 59.35 | 38 |
| 1 | 40 | 100 | 60 | 40 |
| 1 | 42 | 114.56 | 60.33 | 42 |
| 1 | 44 | 135.4 | 60.25 | 44 |
| 1 | 46 | 169.56 | 59.56 | 46 |
| 1 | 48 | 244.95 | 57.8 | 48 |
| 2 | 2 | 7.14 | 9 | 1 |
| 2 | 4 | 10.21 | 13.8 | 2 |
| 2 | 6 | 12.63 | 17.87 | 3 |
| 2 | 8 | 14.74 | 21.56 | 4 |
| 2 | 10 | 16.67 | 25 | 5 |
| 2 | 12 | 18.46 | 28.25 | 6 |
| 2 | 14 | 20.17 | 31.35 | 7 |
| 2 | 16 | 21.82 | 34.33 | 8 |
| 2 | 18 | 23.43 | 37.21 | 9 |
| 2 | 20 | 25 | 40 | 10 |
| 2 | 22 | 26.55 | 42.71 | 11 |
| 2 | 24 | 28.1 | 45.35 | 12 |
| 2 | 26 | 29.64 | 47.93 | 13 |
| 2 | 28 | 31.18 | 50.45 | 14 |
| 2 | 30 | 32.73 | 52.91 | 15 |
| 2 | 32 | 34.3 | 55.32 | 16 |
| 2 | 34 | 35.89 | 57.69 | 17 |
| 2 | 36 | 37.5 | 60 | 18 |
| 2 | 38 | 39.14 | 62.27 | 19 |
| 2 | 40 | 40.82 | 64.49 | 20 |
| 2 | 42 | 42.55 | 66.68 | 21 |
| 2 | 44 | 44.32 | 68.82 | 22 |
| 2 | 46 | 46.15 | 70.92 | 23 |
| 2 | 48 | 48.04 | 72.98 | 24 |
| 2 | 50 | 50 | 75 | 25 |
| 2 | 52 | 52.04 | 76.98 | 26 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 2 | 54 | 54.17 | 78.92 | 27 |
| 2 | 56 | 56.41 | 80.82 | 28 |
| 2 | 58 | 58.76 | 82.68 | 29 |
| 2 | 60 | 61.24 | 84.49 | 30 |
| 2 | 64 | 66.67 | 88 | 32 |
| 2 | 68 | 72.89 | 91.32 | 34 |
| 2 | 72 | 80.18 | 94.45 | 36 |
| 2 | 76 | 88.98 | 97.35 | 38 |
| 2 | 80 | 100 | 100 | 40 |
| 2 | 84 | 114.56 | 102.33 | 42 |
| 2 | 88 | 135.4 | 104.25 | 44 |
| 2 | 92 | 169.56 | 105.56 | 46 |
| 2 | 96 | 244.95 | 105.8 | 48 |
| 3 | 3 | 7.14 | 10 | 1 |
| 3 | 6 | 10.21 | 15.8 | 2 |
| 3 | 9 | 12.63 | 20.87 | 3 |
| 3 | 12 | 14.74 | 25.56 | 4 |
| 3 | 15 | 16.67 | 30 | 5 |
| 3 | 18 | 18.46 | 34.25 | 6 |
| 3 | 21 | 20.17 | 38.35 | 7 |
| 3 | 24 | 21.82 | 42.33 | 8 |
| 3 | 27 | 23.43 | 46.21 | 9 |
| 3 | 30 | 25 | 50 | 10 |
| 3 | 33 | 26.55 | 53.71 | 11 |
| 3 | 36 | 28.1 | 57.35 | 12 |
| 3 | 39 | 29.64 | 60.98 | 13 |
| 3 | 42 | 31.18 | 64.45 | 14 |
| 3 | 45 | 32.73 | 67.91 | 15 |
| 3 | 48 | 34.3 | 71.32 | 16 |
| 3 | 51 | 35.89 | 74.69 | 17 |
| 3 | 54 | 37.5 | 78 | 18 |
| 3 | 57 | 39.14 | 81.27 | 19 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 3 | 60 | 40.82 | 84.49 | 20 |
| 3 | 63 | 42.55 | 87.68 | 21 |
| 3 | 66 | 44.32 | 90.82 | 22 |
| 3 | 69 | 46.15 | 93.93 | 23 |
| 3 | 72 | 48.04 | 96.98 | 24 |
| 3 | 75 | 50 | 100 | 25 |
| 3 | 78 | 52.04 | 102.98 | 26 |
| 3 | 81 | 54.17 | 105.92 | 27 |
| 3 | 84 | 56.41 | 108.82 | 28 |
| 3 | 87 | 58.76 | 111.68 | 29 |
| 3 | 90 | 61.24 | 114.49 | 30 |
| 3 | 96 | 66.67 | 120 | 32 |
| 3 | 102 | 72.89 | 125.32 | 34 |
| 3 | 108 | 80.18 | 130.45 | 36 |
| 3 | 114 | 88.98 | 135.35 | 38 |
| 3 | 120 | 100 | 140 | 40 |
| 3 | 126 | 114.56 | 144.33 | 42 |
| 3 | 132 | 135.4 | 148.25 | 44 |
| 3 | 138 | 169.56 | 151.56 | 46 |
| 3 | 144 | 244.95 | 153.8 | 48 |
| 4 | 4 | 7.14 | 11 | 1 |
| 4 | 8 | 10.21 | 17.8 | 2 |
| 4 | 12 | 12.63 | 23.87 | 3 |
| 4 | 16 | 14.74 | 29.56 | 4 |
| 4 | 20 | 16.67 | 35 | 5 |
| 4 | 24 | 18.46 | 40.25 | 6 |
| 4 | 28 | 20.17 | 45.35 | 7 |
| 4 | 32 | 21.82 | 50.33 | 8 |
| 4 | 36 | 23.43 | 55.21 | 9 |
| 4 | 40 | 25 | 60 | 10 |
| 4 | 44 | 26.55 | 64.71 | 11 |
| 4 | 48 | 28.1 | 69.35 | 12 |
| 4 | 52 | 29.64 | 73.93 | 13 |
| 4 | 56 | 31.18 | 78.45 | 14 |
| 4 | 60 | 32.73 | 82.91 | 15 |
| 4 | 64 | 34.3 | 87.32 | 16 |
| 4 | 68 | 35.89 | 91.69 | 17 |
| 4 | 72 | 37.5 | 96 | 18 |
| 4 | 76 | 39.14 | 100.27 | 19 |
| 4 | 80 | 40.82 | 104.49 | 20 |
| 4 | 84 | 42.55 | 108.68 | 21 |
| 4 | 88 | 44.32 | 112.82 | 22 |
| 4 | 92 | 46.15 | 116.92 | 23 |
| 4 | 96 | 48.04 | 120.98 | 24 |
| 4 | 100 | 50 | 125 | 25 |
| 4 | 104 | 52.04 | 128.98 | 26 |
| 4 | 108 | 54.17 | 132.92 | 27 |
| 4 | 112 | 56.41 | 136.82 | 28 |
| 4 | 116 | 58.76 | 140.68 | 29 |
| 4 | 120 | 61.24 | 144.49 | 30 |
| 4 | 128 | 66.67 | 152 | 32 |
| 4 | 136 | 72.89 | 159.32 | 34 |
| 4 | 144 | 80.18 | 166.45 | 36 |
| 4 | 152 | 88.98 | 173.35 | 38 |
| 4 | 160 | 100 | 180 | 40 |
| 4 | 168 | 114.56 | 186.33 | 42 |
| 4 | 176 | 135.4 | 192.25 | 44 |
| 4 | 184 | 169.56 | 197.56 | 46 |
| 4 | 192 | 244.95 | 201.8 | 48 |
| 5 | 5 | 7.14 | 12 | 1 |
| 5 | 10 | 10.21 | 19.8 | 2 |
| 5 | 15 | 12.63 | 26.87 | 3 |
| 5 | 20 | 14.74 | 33.56 | 4 |
| 5 | 25 | 16.67 | 40 | 5 |
| 5 | 30 | 18.46 | 46.25 | 6 |
| 5 | 35 | 20.17 | 52.35 | 7 |
| 5 | 40 | 21.82 | 58.33 | 8 |
| 5 | 45 | 23.43 | 64.21 | 9 |
| 5 | 50 | 25 | 70 | 10 |
| 5 | 55 | 26.55 | 75.71 | 11 |
| 5 | 60 | 28.1 | 81.35 | 12 |
| 5 | 65 | 29.64 | 86.93 | 13 |
| 5 | 70 | 31.18 | 92.45 | 14 |
| 5 | 75 | 32.73 | 97.91 | 15 |
| 5 | 80 | 34.3 | 103.32 | 16 |
| 5 | 85 | 35.89 | 108.69 | 17 |
| 5 | 90 | 37.5 | 114 | 18 |
| 5 | 95 | 39.14 | 119.27 | 19 |
| 5 | 100 | 40.82 | 124.49 | 20 |
| 5 | 105 | 42.55 | 129.68 | 21 |
| 5 | 110 | 44.32 | 134.82 | 22 |
| 5 | 115 | 46.15 | 139.92 | 23 |
| 5 | 120 | 48.04 | 144.98 | 24 |
| 5 | 125 | 50 | 150 | 25 |
| 5 | 130 | 52.04 | 154.98 | 26 |
| 5 | 135 | 54.17 | 159.92 | 27 |
| 5 | 140 | 56.41 | 164.82 | 28 |
| 5 | 145 | 58.76 | 169.68 | 29 |
| 5 | 150 | 61.24 | 174.49 | 30 |
| 5 | 160 | 66.67 | 184 | 32 |
| 5 | 170 | 72.89 | 193.32 | 34 |
| 5 | 180 | 80.18 | 202.45 | 36 |
| 5 | 190 | 88.98 | 211.35 | 38 |
| 5 | 200 | 100 | 220 | 40 |
| 5 | 210 | 114.56 | 228.33 | 42 |
| 5 | 220 | 135.4 | 236.25 | 44 |
| 5 | 230 | 169.56 | 243.56 | 46 |
| 5 | 240 | 244.95 | 249.8 | 48 |
| 6 | 6 | 7.14 | 13 | 1 |
| 6 | 12 | 10.21 | 21.8 | 2 |
| 6 | 18 | 12.63 | 29.87 | 3 |
| 6 | 24 | 14.74 | 37.56 | 4 |
| 6 | 30 | 16.67 | 45 | 5 |
| 6 | 36 | 18.46 | 52.25 | 6 |
| 6 | 42 | 20.17 | 59.35 | 7 |
| 6 | 48 | 21.82 | 66.33 | 8 |
| 6 | 54 | 23.43 | 73.21 | 9 |
| 6 | 60 | 25 | 80 | 10 |
| 6 | 66 | 26.55 | 86.71 | 11 |
| 6 | 72 | 28.1 | 93.35 | 12 |
| 6 | 78 | 29.64 | 99.93 | 13 |
| 6 | 84 | 31.18 | 106.45 | 14 |
| 6 | 90 | 32.73 | 112.91 | 15 |
| 6 | 96 | 34.3 | 119.32 | 16 |
| 6 | 102 | 35.89 | 125.69 | 17 |
| 6 | 108 | 37.5 | 132 | 18 |
| 6 | 114 | 39.14 | 138.27 | 19 |
| 6 | 120 | 40.82 | 144.49 | 20 |
| 6 | 126 | 42.55 | 150.68 | 21 |
| 6 | 132 | 44.32 | 156.82 | 22 |
| 6 | 138 | 46.15 | 162.92 | 23 |
| 6 | 144 | 48.04 | 168.98 | 24 |
| 6 | 150 | 50 | 175 | 25 |
| 6 | 156 | 52.04 | 180.98 | 26 |
| 6 | 162 | 54.17 | 186.92 | 27 |
| 6 | 168 | 56.41 | 192.82 | 28 |
| 6 | 174 | 58.76 | 198.68 | 29 |
| 6 | 180 | 61.24 | 204.49 | 30 |
| 6 | 192 | 66.67 | 216 | 32 |
| 6 | 204 | 72.89 | 227.32 | 34 |
| 6 | 216 | 80.18 | 238.45 | 36 |
| 6 | 228 | 88.98 | 249.35 | 38 |
| 6 | 240 | 100 | 260 | 40 |
| 6 | 252 | 114.56 | 270.33 | 42 |
| 6 | 264 | 135.4 | 280.25 | 44 |
| 6 | 276 | 169.56 | 289.56 | 46 |
| 6 | 288 | 244.95 | 297.8 | 48 |
| 7 | 7 | 7.14 | 14 | 1 |
| 7 | 14 | 10.21 | 23.8 | 2 |
| 7 | 21 | 12.63 | 32.87 | 3 |
| 7 | 28 | 14.74 | 41.56 | 4 |
| 7 | 35 | 16.67 | 50 | 5 |
| 7 | 42 | 18.46 | 58.25 | 6 |
| 7 | 49 | 20.17 | 66.35 | 7 |
| 7 | 56 | 21.82 | 74.33 | 8 |
| 7 | 63 | 23.43 | 82.21 | 9 |
| 7 | 70 | 25 | 90 | 10 |
| 7 | 77 | 26.55 | 97.71 | 11 |
| 7 | 84 | 28.1 | 105.35 | 12 |
| 7 | 91 | 29.64 | 112.93 | 13 |
| 7 | 98 | 31.18 | 120.45 | 14 |
| 7 | 105 | 32.73 | 127.91 | 15 |
| 7 | 112 | 34.3 | 135.32 | 16 |
| 7 | 119 | 35.89 | 142.69 | 17 |
| 7 | 126 | 37.5 | 150 | 18 |
| 7 | 133 | 39.14 | 157.27 | 19 |
| 7 | 140 | 40.82 | 164.49 | 20 |
| 7 | 147 | 42.55 | 171.68 | 21 |
| 7 | 154 | 44.32 | 178.82 | 22 |
| 7 | 161 | 46.15 | 185.92 | 23 |
| 7 | 168 | 48.04 | 192.98 | 24 |
| 7 | 175 | 50 | 200 | 25 |
| 7 | 182 | 52.04 | 206.98 | 26 |
| 7 | 189 | 54.17 | 213.92 | 27 |
| 7 | 196 | 56.41 | 220.82 | 28 |
| 7 | 203 | 58.76 | 227.68 | 29 |
| 7 | 210 | 61.24 | 234.49 | 30 |
| 7 | 224 | 66.67 | 248 | 32 |
| 7 | 238 | 72.89 | 261.32 | 34 |
| 7 | 252 | 80.18 | 274.45 | 36 |
| 7 | 266 | 88.98 | 287.35 | 38 |
| 7 | 280 | 100 | 300 | 40 |
| 7 | 294 | 114.56 | 312.33 | 42 |
| 7 | 308 | 135.4 | 324.25 | 44 |
| 7 | 322 | 169.56 | 335.56 | 46 |
| 7 | 336 | 244.95 | 345.8 | 48 |
| 8 | 8 | 7.14 | 15 | 1 |
| 8 | 16 | 10.21 | 25.8 | 2 |
| 8 | 24 | 12.63 | 35.87 | 3 |
| 8 | 32 | 14.74 | 45.56 | 4 |
| 8 | 40 | 16.67 | 55 | 5 |
| 8 | 48 | 18.46 | 64.25 | 6 |
| 8 | 56 | 20.17 | 73.35 | 7 |
| 8 | 64 | 21.82 | 82.33 | 8 |
| 8 | 72 | 23.43 | 91.21 | 9 |
| 8 | 80 | 25 | 100 | 10 |
| 8 | 88 | 26.55 | 108.71 | 11 |
| 8 | 96 | 28.1 | 117.35 | 12 |
| 8 | 104 | 29.64 | 125.93 | 13 |
| 8 | 112 | 31.18 | 134.45 | 14 |
| 8 | 120 | 32.73 | 142.91 | 15 |
| 8 | 128 | 34.3 | 151.32 | 16 |
| 8 | 136 | 35.89 | 159.69 | 17 |
| 8 | 144 | 37.5 | 168 | 18 |
| 8 | 152 | 39.14 | 176.27 | 19 |
| 8 | 160 | 40.82 | 184.49 | 20 |
| 8 | 168 | 42.55 | 192.68 | 21 |
| 8 | 176 | 44.32 | 200.82 | 22 |
| 8 | 184 | 46.15 | 208.92 | 23 |
| 8 | 192 | 48.04 | 216.98 | 24 |
| 8 | 200 | 50 | 225 | 25 |
| 8 | 208 | 52.04 | 232.98 | 26 |
| 8 | 216 | 54.17 | 240.92 | 27 |
| 8 | 224 | 56.41 | 248.82 | 28 |
| 8 | 232 | 58.76 | 256.68 | 29 |
| 8 | 240 | 61.24 | 264.49 | 30 |
| 8 | 256 | 66.67 | 280 | 32 |
| 8 | 272 | 72.89 | 295.32 | 34 |
| 8 | 288 | 80.18 | 310.45 | 36 |
| 8 | 304 | 88.98 | 325.35 | 38 |

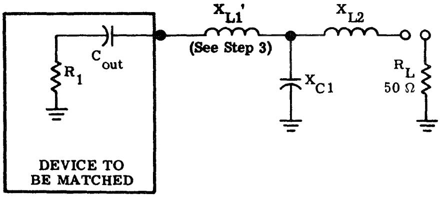
| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 8 | 320 | 100 | 340 | 40 |
| 8 | 336 | 114.56 | 354.33 | 42 |
| 8 | 352 | 135.4 | 368.25 | 44 |
| 8 | 368 | 169.56 | 381.56 | 46 |
| 8 | 384 | 244.95 | 393.8 | 48 |
| 9 | 9 | 7.14 | 16 | 1 |
| 9 | 18 | 10.21 | 27.8 | 2 |
| 9 | 27 | 12.63 | 38.87 | 3 |
| 9 | 36 | 14.74 | 49.56 | 4 |
| 9 | 45 | 16.67 | 60 | 5 |
| 9 | 54 | 18.46 | 70.25 | 6 |
| 9 | 63 | 20.17 | 80.35 | 7 |
| 9 | 72 | 21.82 | 90.33 | 8 |
| 9 | 81 | 23.43 | 100.21 | 9 |
| 9 | 90 | 25 | 110 | 10 |
| 9 | 99 | 26.55 | 119.71 | 11 |
| 9 | 108 | 28.1 | 129.35 | 12 |
| 9 | 117 | 29.64 | 138.93 | 13 |
| 9 | 126 | 31.18 | 148.45 | 14 |
| 9 | 135 | 32.73 | 157.91 | 15 |
| 9 | 144 | 34.3 | 167.32 | 16 |
| 9 | 153 | 35.89 | 176.69 | 17 |
| 9 | 162 | 37.5 | 186 | 18 |
| 9 | 171 | 39.17 | 195.27 | 19 |
| 9 | 180 | 40.82 | 204.49 | 20 |
| 9 | 189 | 42.55 | 213.68 | 21 |
| 9 | 198 | 44.32 | 222.82 | 22 |
| 9 | 207 | 46.15 | 231.92 | 23 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 9 | 414 | 169.56 | 427.56 | 46 |
| 9 | 432 | 244.95 | 441.8 | 48 |
| 9 | 216 | 48.04 | 240.98 | 24 |
| 9 | 225 | 50 | 250 | 25 |
| 9 | 234 | 52.04 | 258.98 | 26 |
| 9 | 243 | 54.17 | 267.92 | 27 |
| 9 | 252 | 56.41 | 276.82 | 28 |
| 9 | 261 | 58.76 | 285.88 | 29 |
| 9 | 270 | 61.24 | 294.49 | 30 |
| 9 | 288 | 66.67 | 312 | 32 |
| 9 | 306 | 72.89 | 329.32 | 34 |
| 9 | 324 | 80.18 | 346.45 | 36 |
| 9 | 342 | 88.98 | 363.35 | 38 |
| 9 | 360 | 100 | 380 | 40 |
| 9 | 378 | 114.56 | 396.33 | 42 |
| 9 | 396 | 135.4 | 412.25 | 44 |
| 10 | 10 | 7.14 | 17 | 1 |
| 10 | 20 | 10.21 | 29.8 | 2 |
| 10 | 30 | 12.63 | 41.87 | 3 |
| 10 | 40 | 14.74 | 53.56 | 4 |
| 10 | 50 | 16.67 | 65 | 5 |
| 10 | 60 | 18.46 | 76.25 | 6 |
| 10 | 70 | 20.17 | 87.35 | 7 |
| 10 | 80 | 21.82 | 98.33 | 8 |
| 10 | 90 | 23.43 | 109.21 | 9 |
| 10 | 100 | 25 | 120 | 10 |
| 10 | 110 | 26.55 | 130.71 | 11 |

| Q | $X_{C1}$ | $X_{C2}$ | $X_{L2}$ | $R_1$ |
|---|---|---|---|---|
| 10 | 120 | 28.1 | 141.35 | 12 |
| 10 | 130 | 29.64 | 151.93 | 13 |
| 10 | 140 | 31.18 | 162.45 | 14 |
| 10 | 150 | 32.73 | 172.91 | 15 |
| 10 | 160 | 34.3 | 183.32 | 16 |
| 10 | 170 | 35.89 | 193.69 | 17 |
| 10 | 180 | 37.5 | 204 | 18 |
| 10 | 190 | 39.14 | 214.27 | 19 |
| 10 | 200 | 40.82 | 224.49 | 20 |
| 10 | 210 | 42.55 | 234.68 | 21 |
| 10 | 220 | 44.32 | 244.82 | 22 |
| 10 | 230 | 46.15 | 254.92 | 23 |
| 10 | 240 | 48.04 | 264.98 | 24 |
| 10 | 250 | 50 | 275 | 25 |
| 10 | 260 | 52.04 | 284.98 | 26 |
| 10 | 270 | 54.17 | 294.92 | 27 |
| 10 | 280 | 56.41 | 304.82 | 28 |
| 10 | 290 | 58.76 | 314.68 | 29 |
| 10 | 300 | 61.24 | 324.49 | 30 |
| 10 | 320 | 66.67 | 344 | 32 |
| 10 | 340 | 72.89 | 363.32 | 34 |
| 10 | 360 | 80.18 | 382.45 | 36 |
| 10 | 380 | 88.98 | 401.35 | 38 |
| 10 | 400 | 100 | 420 | 40 |
| 10 | 420 | 114.56 | 438.33 | 42 |
| 10 | 440 | 135.4 | 456.25 | 44 |
| 10 | 460 | 169.56 | 473.56 | 46 |
| 10 | 480 | 244.95 | 489.8 | 48 |

## NETWORK D

The following is a computer solution for an RF "Tee" matching network.
Tuning is accomplished by using a variable capacitor for $C_1$. Variable matching may also be accomplished by increasing $X_{L2}$ and adding an equal amount of $X_C$ in series in the form of a variable capacitor.




TO DESIGN A NETWORK USING THE TABLES

1. Define Q, in column one, as $X_{L1}/R_1$.
2. For an $R_1$ to be matched and a desired Q, read the reactances of the network components from the charts.
3. $X_{L1}'$ is equal to the quantity $X_{L1}$ obtained from the tables plus $|X_{C_{out}}|$.
4. This completes the network.

| Q | $X_{L1}$ | $X_{L2}$ | $X_{C1}$ | $R_1$ |
|---|---|---|---|---|
| 1 | 26 | 10 | 43.33 | 26 |
| 1 | 27 | 14.14 | 42.09 | 27 |
| 1 | 28 | 17.32 | 41.59 | 28 |
| 1 | 29 | 20 | 41.43 | 29 |
| 1 | 30 | 22.36 | 41.46 | 30 |
| 1 | 32 | 26.46 | 41.85 | 32 |
| 1 | 34 | 30 | 42.5 | 34 |
| 1 | 36 | 33.17 | 43.29 | 36 |
| 1 | 38 | 36.06 | 44.16 | 38 |
| 1 | 40 | 38.72 | 45.08 | 40 |
| 1 | 42 | 41.23 | 46.04 | 42 |
| 1 | 44 | 43.59 | 47.01 | 44 |
| 1 | 46 | 45.83 | 48 | 46 |
| 1 | 48 | 47.96 | 49 | 48 |
| 1 | 50 | 50 | 50 | 50 |
| 1 | 55 | 54.77 | 52.49 | 55 |
| 1 | 60 | 59.16 | 54.96 | 60 |
| 1 | 65 | 63.25 | 57.4 | 65 |
| 1 | 70 | 67.08 | 69.79 | 70 |
| 1 | 75 | 70.71 | 62.13 | 75 |
| 1 | 80 | 74.16 | 64.43 | 80 |
| 1 | 85 | 77.46 | 66.69 | 85 |
| 1 | 90 | 80.62 | 68.9 | 90 |
| 1 | 95 | 83.67 | 71.07 | 95 |
| 1 | 100 | 86.6 | 73.21 | 100 |
| 1 | 125 | 100 | 83.33 | 125 |
| 1 | 150 | 111.8 | 92.71 | 150 |

| Q | $X_{L1}$ | $X_{L2}$ | $X_{C1}$ | $R_1$ |
|---|---|---|---|---|
| 1 | 175 | 122.47 | 101.46 | 175 |
| 1 | 200 | 132.29 | 109.72 | 200 |
| 1 | 225 | 141.42 | 117.54 | 225 |
| 1 | 250 | 150 | 125 | 250 |
| 1 | 275 | 158.11 | 132.14 | 275 |
| 1 | 300 | 165.83 | 139 | 300 |
| 2 | 22 | 15.81 | 23.75 | 11 |
| 2 | 24 | 22.36 | 24.52 | 12 |
| 2 | 26 | 27.39 | 25.51 | 13 |
| 2 | 28 | 31.62 | 26.59 | 14 |
| 2 | 30 | 35.36 | 27.7 | 15 |
| 2 | 32 | 38.73 | 28.83 | 16 |
| 2 | 34 | 41.83 | 29.96 | 17 |
| 2 | 36 | 44.72 | 31.09 | 18 |
| 2 | 38 | 47.43 | 32.22 | 19 |
| 2 | 40 | 50 | 33.33 | 20 |
| 2 | 42 | 52.44 | 34.44 | 21 |
| 2 | 44 | 54.77 | 35.54 | 22 |
| 2 | 46 | 57.01 | 36.62 | 23 |
| 2 | 48 | 59.16 | 37.7 | 24 |
| 2 | 50 | 61.24 | 38.76 | 25 |
| 2 | 52 | 63.25 | 39.82 | 26 |
| 2 | 54 | 65.19 | 40.86 | 27 |
| 2 | 56 | 67.08 | 41.9 | 28 |
| 2 | 58 | 68.92 | 42.92 | 29 |
| 2 | 60 | 70.71 | 43.93 | 30 |
| 2 | 64 | 74.16 | 45.93 | 32 |

| Q | $X_{L1}$ | $X_{L2}$ | $X_{C1}$ | $R_1$ |
|---|---|---|---|---|
| 2 | 68 | 77.46 | 47.9 | 34 |
| 2 | 72 | 80.62 | 49.83 | 36 |
| 2 | 76 | 83.67 | 51.72 | 38 |
| 2 | 80 | 86.6 | 53.59 | 40 |
| 2 | 84 | 89.44 | 55.43 | 42 |
| 2 | 88 | 92.2 | 57.23 | 44 |
| 2 | 92 | 94.87 | 59.01 | 46 |
| 2 | 96 | 97.47 | 60.77 | 48 |
| 2 | 100 | 100 | 62.5 | 50 |
| 2 | 110 | 106.07 | 66.73 | 55 |
| 2 | 120 | 111.8 | 70.82 | 60 |
| 2 | 130 | 117.26 | 74.8 | 65 |
| 2 | 140 | 122.47 | 78.66 | 70 |
| 2 | 150 | 127.48 | 82.43 | 75 |
| 2 | 160 | 132.29 | 86.1 | 80 |
| 2 | 170 | 136.93 | 89.69 | 85 |
| 2 | 180 | 141.42 | 93.2 | 90 |
| 2 | 190 | 145.77 | 96.63 | 95 |
| 2 | 200 | 150 | 100 | 100 |
| 2 | 250 | 169.56 | 115.93 | 125 |
| 2 | 300 | 187.08 | 130.62 | 150 |
| 2 | 350 | 203.1 | 144.34 | 175 |
| 2 | 400 | 217.94 | 157.26 | 200 |
| 2 | 450 | 231.84 | 169.51 | 225 |
| 2 | 500 | 244.95 | 181.19 | 250 |
| 2 | 550 | 257.39 | 192.37 | 275 |
| 2 | 600 | 269.26 | 203.11 | 300 |

| Q | $X_{L1}$ | $X_{L2}$ | $X_{C1}$ | $R_1$ |
|---|---|---|---|---|
| 3 | 18 | 22.36 | 17.41 | 6 |
| 3 | 21 | 31.62 | 19.27 | 7 |
| 3 | 24 | 38.73 | 21.19 | 8 |
| 3 | 27 | 44.72 | 23.11 | 9 |
| 3 | 30 | 50 | 25 | 10 |
| 3 | 33 | 54.77 | 26.86 | 11 |
| 3 | 36 | 59.16 | 28.69 | 12 |
| 3 | 39 | 63.25 | 30.48 | 13 |
| 3 | 42 | 67.08 | 32.25 | 14 |
| 3 | 45 | 70.71 | 33.98 | 15 |
| 3 | 48 | 74.16 | 35.69 | 16 |
| 3 | 51 | 77.46 | 37.37 | 17 |
| 3 | 54 | 80.62 | 39.02 | 18 |
| 3 | 57 | 83.67 | 40.66 | 19 |
| 3 | 60 | 86.6 | 42.26 | 20 |
| 3 | 63 | 89.44 | 43.85 | 21 |
| 3 | 66 | 92.2 | 45.42 | 22 |
| 3 | 69 | 94.87 | 46.96 | 23 |
| 3 | 72 | 97.47 | 48.49 | 24 |
| 3 | 75 | 100 | 50 | 25 |
| 3 | 78 | 102.47 | 51.49 | 26 |
| 3 | 81 | 104.88 | 52.97 | 27 |
| 3 | 84 | 107.24 | 54.42 | 28 |
| 3 | 87 | 109.54 | 55.87 | 29 |
| 3 | 90 | 111.8 | 57.29 | 30 |
| 3 | 96 | 116.19 | 60.11 | 32 |
| 3 | 102 | 120.42 | 62.87 | 34 |
| 3 | 108 | 124.5 | 65.57 | 36 |
| 3 | 114 | 128.45 | 68.23 | 38 |
| 3 | 120 | 132.29 | 70.85 | 40 |
| 3 | 126 | 136.01 | 73.42 | 42 |
| 3 | 132 | 139.64 | 75.96 | 44 |
| 3 | 138 | 143.18 | 78.45 | 46 |
| 3 | 144 | 146.63 | 80.91 | 48 |
| 3 | 150 | 150 | 83.33 | 50 |
| 3 | 165 | 158.11 | 89.25 | 55 |
| 3 | 180 | 165.83 | 94.99 | 60 |
| 3 | 195 | 173.21 | 100.56 | 65 |
| 3 | 210 | 180.28 | 105.97 | 70 |
| 3 | 225 | 187.08 | 111.25 | 75 |
| 3 | 240 | 193.65 | 116.4 | 80 |
| 3 | 255 | 200 | 121.43 | 85 |
| 3 | 270 | 206.16 | 126.35 | 90 |
| 3 | 285 | 212.13 | 131.17 | 95 |
| 3 | 300 | 217.94 | 135.89 | 100 |
| 3 | 375 | 244.95 | 158.25 | 125 |
| 3 | 450 | 269.26 | 178.89 | 150 |
| 3 | 525 | 291.55 | 198.17 | 175 |
| 3 | 600 | 312.25 | 216.33 | 200 |
| 3 | 675 | 331.66 | 233.57 | 225 |
| 3 | 750 | 350 | 250 | 250 |
| 3 | 825 | 367.42 | 265.74 | 275 |
| 3 | 900 | 384.06 | 280.87 | 300 |
| 4 | 12 | 7.07 | 12.31 | 3 |
| 4 | 16 | 30 | 14.78 | 4 |
| 4 | 20 | 41.83 | 17.57 | 5 |
| 4 | 24 | 50.99 | 20.32 | 6 |
| 4 | 28 | 58.74 | 23 | 7 |
| 4 | 32 | 65.57 | 25.6 | 8 |
| 4 | 36 | 71.76 | 28.15 | 9 |
| 4 | 40 | 77.46 | 30.64 | 10 |
| 4 | 44 | 82.76 | 33.07 | 11 |
| 4 | 48 | 87.75 | 35.45 | 12 |
| 4 | 52 | 92.47 | 37.78 | 13 |
| 4 | 56 | 96.95 | 40.07 | 14 |
| 4 | 60 | 101.24 | 42.32 | 15 |
| 4 | 64 | 105.36 | 44.54 | 16 |
| 4 | 68 | 109.32 | 46.72 | 17 |
| 4 | 72 | 113.14 | 48.86 | 18 |
| 4 | 76 | 116.83 | 50.97 | 19 |
| 4 | 80 | 120.42 | 53.06 | 20 |
| 4 | 84 | 123.9 | 55.11 | 21 |
| 4 | 88 | 127.28 | 57.14 | 22 |
| 4 | 92 | 130.58 | 59.14 | 23 |
| 4 | 96 | 133.79 | 61.12 | 24 |
| 4 | 100 | 136.93 | 63.07 | 25 |
| 4 | 104 | 140 | 65 | 26 |
| 4 | 108 | 143 | 66.91 | 27 |
| 4 | 112 | 145.95 | 68.8 | 28 |
| 4 | 116 | 148.83 | 70.67 | 29 |
| 4 | 120 | 151.66 | 72.51 | 30 |
| 4 | 128 | 157.16 | 76.16 | 32 |
| 4 | 136 | 162.48 | 79.73 | 34 |
| 4 | 144 | 167.63 | 83.24 | 36 |
| 4 | 152 | 172.63 | 86.68 | 38 |
| 4 | 160 | 177.48 | 90.07 | 40 |
| 4 | 168 | 182.21 | 93.4 | 42 |
| 4 | 176 | 186.82 | 96.69 | 44 |
| 4 | 184 | 191.31 | 99.92 | 46 |
| 4 | 192 | 195.7 | 103.11 | 48 |
| 4 | 200 | 200 | 106.25 | 50 |
| 4 | 220 | 210.36 | 113.93 | 55 |
| 4 | 240 | 220.23 | 121.36 | 60 |
| 4 | 260 | 229.67 | 128.59 | 65 |
| 4 | 280 | 238.75 | 135.61 | 70 |
| 4 | 300 | 247.49 | 142.46 | 75 |
| 4 | 320 | 255.93 | 148.15 | 80 |
| 4 | 340 | 264.1 | 155.68 | 85 |
| 4 | 360 | 272.03 | 162.07 | 90 |
| 4 | 380 | 279.73 | 168.32 | 95 |
| 4 | 400 | 287.23 | 174.46 | 100 |
| 4 | 500 | 322.1 | 203.5 | 125 |
| 4 | 600 | 353.55 | 230.33 | 150 |
| 4 | 700 | 382.43 | 255.4 | 175 |
| 4 | 800 | 409.27 | 279.02 | 200 |
| 4 | 900 | 434.45 | 301.44 | 225 |
| 4 | 1000 | 458.26 | 322.82 | 250 |
| 4 | 1100 | 480.88 | 343.3 | 275 |
| 4 | 1200 | 502.49 | 362.99 | 300 |
| 5 | 10 | 10 | 10 | 2 |
| 5 | 15 | 37.42 | 13.57 | 3 |
| 5 | 20 | 51.96 | 17.22 | 4 |
| 5 | 25 | 63.25 | 20.75 | 5 |
| 5 | 30 | 72.8 | 24.16 | 6 |
| 5 | 35 | 81.24 | 27.47 | 7 |
| 5 | 40 | 88.88 | 30.69 | 8 |
| 5 | 45 | 95.92 | 33.82 | 9 |
| 5 | 50 | 102.47 | 36.88 | 10 |
| 5 | 55 | 108.63 | 39.87 | 11 |
| 5 | 60 | 114.46 | 42.8 | 12 |
| 5 | 65 | 120 | 45.68 | 13 |
| 5 | 70 | 125.3 | 48.49 | 14 |
| 5 | 75 | 130.38 | 51.26 | 15 |
| 5 | 80 | 135.28 | 53.99 | 16 |
| 5 | 85 | 140 | 56.67 | 17 |
| 5 | 90 | 144.57 | 59.31 | 18 |
| 5 | 95 | 149 | 61.91 | 19 |
| 5 | 100 | 153.3 | 64.47 | 20 |
| 5 | 105 | 157.48 | 67 | 21 |
| 5 | 110 | 161.55 | 69.49 | 22 |
| 5 | 115 | 165.53 | 71.96 | 23 |
| 5 | 120 | 169.41 | 74.39 | 24 |
| 5 | 125 | 173.21 | 76.79 | 25 |
| 5 | 130 | 176.92 | 79.17 | 26 |
| 5 | 135 | 180.55 | 81.52 | 27 |
| 5 | 140 | 184.12 | 83.85 | 28 |
| 5 | 145 | 187.62 | 86.15 | 29 |
| 5 | 150 | 191.05 | 88.43 | 30 |
| 5 | 160 | 197.74 | 92.91 | 32 |
| 5 | 170 | 204.21 | 97.31 | 34 |
| 5 | 180 | 210.48 | 101.63 | 36 |
| 5 | 190 | 216.56 | 105.88 | 38 |
| 5 | 200 | 222.49 | 110.06 | 40 |
| 5 | 210 | 228.25 | 114.17 | 42 |
| 5 | 220 | 233.88 | 118.21 | 44 |
| 5 | 230 | 239.37 | 122.2 | 46 |
| 5 | 240 | 244.74 | 126.13 | 48 |
| 5 | 250 | 260 | 130 | 50 |
| 5 | 275 | 262.68 | 139.46 | 55 |
| 5 | 300 | 274.77 | 148.64 | 60 |
| 5 | 325 | 286.36 | 157.54 | 65 |
| 5 | 350 | 297.49 | 166.21 | 70 |
| 5 | 375 | 308.22 | 174.66 | 75 |
| 5 | 400 | 318.59 | 182.91 | 80 |
| 5 | 425 | 328.63 | 190.97 | 85 |
| 5 | 450 | 338.38 | 198.85 | 90 |
| 5 | 475 | 347.85 | 206.57 | 95 |
| 5 | 500 | 357.07 | 214.14 | 100 |
| 5 | 625 | 400 | 250 | 125 |
| 5 | 750 | 438.75 | 283.12 | 150 |
| 5 | 875 | 474.34 | 314.08 | 175 |
| 5 | 1000 | 507.44 | 343.26 | 200 |
| 5 | 1125 | 538.52 | 670.95 | 225 |
| 5 | 1250 | 567.89 | 397.36 | 250 |
| 5 | 1375 | 595.82 | 422.67 | 275 |
| 5 | 1500 | 622.49 | 446.99 | 300 |
| 6 | 12 | 34.64 | 11.06 | 2 |
| 6 | 18 | 55.23 | 15.62 | 3 |
| 6 | 24 | 70 | 20 | 4 |
| 6 | 30 | 82.16 | 24.2 | 5 |
| 6 | 36 | 92.74 | 28.26 | 6 |
| 6 | 42 | 102.23 | 32.2 | 7 |
| 6 | 48 | 110.91 | 36.02 | 8 |
| 6 | 54 | 118.95 | 39.74 | 9 |
| 6 | 60 | 126.49 | 43.38 | 10 |
| 6 | 66 | 133.6 | 46.93 | 11 |
| 6 | 72 | 140.36 | 50.41 | 12 |
| 6 | 78 | 146.8 | 53.83 | 13 |
| 6 | 84 | 152.97 | 57.18 | 14 |
| 6 | 90 | 158.9 | 60.47 | 15 |
| 6 | 96 | 164.62 | 63.71 | 16 |
| 6 | 102 | 170.15 | 66.89 | 17 |
| 6 | 108 | 175.5 | 70.03 | 18 |
| 6 | 114 | 180.69 | 73.12 | 19 |
| 6 | 120 | 185.74 | 76.17 | 20 |
| 6 | 126 | 190.66 | 79.18 | 21 |
| 6 | 132 | 195.45 | 82.15 | 22 |
| 6 | 138 | 200.12 | 85.08 | 23 |
| 6 | 144 | 204.69 | 87.97 | 24 |
| 6 | 150 | 209.17 | 90.83 | 25 |
| 6 | 156 | 213.54 | 93.66 | 26 |
| 6 | 162 | 217.83 | 96.46 | 27 |
| 6 | 168 | 222.04 | 99.23 | 28 |
| 6 | 174 | 226.16 | 101.96 | 29 |
| 6 | 180 | 230.22 | 104.67 | 30 |
| 6 | 192 | 238.12 | 110.01 | 32 |
| 6 | 204 | 245.76 | 115.25 | 34 |
| 6 | 216 | 253.18 | 120.39 | 36 |
| 6 | 228 | 260.38 | 125.45 | 38 |
| 6 | 240 | 267.39 | 130.42 | 40 |
| 6 | 252 | 274.23 | 135.31 | 42 |
| 6 | 264 | 280.89 | 140.13 | 44 |
| 6 | 276 | 287.4 | 144.88 | 46 |
| 6 | 288 | 293.77 | 149.55 | 48 |
| 6 | 300 | 300 | 154.17 | 50 |
| 6 | 330 | 315.04 | 165.44 | 55 |
| 6 | 360 | 329.39 | 176.36 | 60 |
| 6 | 390 | 343.15 | 186.97 | 65 |
| 6 | 420 | 356.37 | 197.3 | 70 |
| 6 | 450 | 369.12 | 207.36 | 75 |
| 6 | 480 | 381.44 | 217.19 | 80 |
| 6 | 510 | 393.38 | 226.79 | 85 |
| 6 | 540 | 404.97 | 236.18 | 90 |
| 6 | 570 | 416.23 | 245.38 | 95 |
| 6 | 600 | 427.2 | 254.4 | 100 |
| 6 | 750 | 478.28 | 297.13 | 125 |
| 6 | 900 | 524.4 | 336.61 | 150 |
| 6 | 1050 | 566.79 | 373.5 | 175 |
| 6 | 1200 | 606.22 | 408.29 | 200 |
| 6 | 1350 | 643.23 | 441.3 | 225 |
| 6 | 1500 | 678.23 | 472.79 | 250 |
| 6 | 1650 | 711.51 | 502.96 | 275 |
| 6 | 1800 | 743.3 | 531.96 | 300 |
| 7 | 14 | 50 | 12.5 | 2 |
| 7 | 21 | 70.71 | 17.83 | 3 |
| 7 | 28 | 86.6 | 22.9 | 4 |
| 7 | 35 | 100 | 27.78 | 5 |
| 7 | 42 | 111.8 | 32.48 | 6 |
| 7 | 49 | 122.47 | 37.04 | 7 |
| 7 | 56 | 132.29 | 41.47 | 8 |
| 7 | 63 | 141.42 | 45.79 | 9 |
| 7 | 70 | 150 | 50 | 10 |
| 7 | 77 | 158.11 | 54.12 | 11 |
| 7 | 84 | 165.83 | 58.16 | 12 |
| 7 | 91 | 173.21 | 62.12 | 13 |
| 7 | 98 | 180.28 | 66 | 14 |
| 7 | 105 | 187.08 | 69.82 | 15 |
| 7 | 112 | 193.65 | 73.58 | 16 |

| Q | $X_{L1}$ | $X_{L2}$ | $X_{C1}$ | $R_1$ |
|---|---|---|---|---|
| 7 | 119 | 200 | 77.27 | 17 |
| 7 | 126 | 206.16 | 80.91 | 18 |
| 7 | 133 | 212.13 | 84.5 | 19 |
| 7 | 140 | 217.94 | 88.04 | 20 |
| 7 | 147 | 223.61 | 91.53 | 21 |
| 7 | 154 | 229.13 | 94.97 | 22 |
| 7 | 161 | 234.52 | 98.37 | 23 |
| 7 | 168 | 239.79 | 101.73 | 24 |
| 7 | 175 | 244.95 | 105.05 | 25 |
| 7 | 182 | 250 | 108.33 | 26 |
| 7 | 189 | 254.95 | 111.58 | 27 |
| 7 | 196 | 259.81 | 114.79 | 28 |
| 7 | 203 | 264.58 | 117.97 | 29 |
| 7 | 210 | 269.26 | 121.11 | 30 |
| 7 | 224 | 278.39 | 127.31 | 32 |
| 7 | 238 | 287.23 | 133.39 | 34 |
| 7 | 252 | 295.8 | 139.36 | 36 |
| 7 | 266 | 304.14 | 145.23 | 38 |
| 7 | 280 | 312.25 | 151 | 40 |
| 7 | 294 | 320.16 | 156.68 | 42 |
| 7 | 308 | 327.87 | 162.27 | 44 |
| 7 | 322 | 335.41 | 167.78 | 46 |
| 7 | 336 | 342.78 | 173.21 | 48 |
| 7 | 350 | 350 | 178.57 | 50 |
| 7 | 385 | 367.42 | 191.66 | 55 |
| 7 | 420 | 384.06 | 204.34 | 60 |
| 7 | 455 | 400 | 216.67 | 65 |
| 7 | 490 | 415.33 | 228.66 | 70 |
| 7 | 525 | 430.12 | 240.35 | 75 |
| 7 | 560 | 444.41 | 251.76 | 80 |
| 7 | 595 | 458.86 | 262.91 | 85 |
| 7 | 630 | 471.7 | 273.82 | 90 |
| 7 | 665 | 484.77 | 284.51 | 95 |
| 7 | 700 | 497.49 | 294.99 | 100 |
| 7 | 875 | 556.78 | 344.63 | 125 |
| 7 | 1050 | 610.33 | 390.49 | 150 |
| 7 | 1225 | 659.55 | 433.36 | 175 |
| 7 | 1400 | 705.34 | 473.78 | 200 |
| 7 | 1575 | 748.33 | 512.14 | 225 |
| 7 | 1750 | 788.99 | 548.73 | 250 |
| 7 | 1925 | 827.65 | 583.79 | 275 |
| 7 | 2100 | 864.58 | 617.5 | 300 |
| 8 | 8 | 27.39 | 7.6 | 1 |
| 8 | 16 | 63.25 | 14.03 | 2 |
| 8 | 24 | 85.15 | 20.1 | 3 |
| 8 | 32 | 102.47 | 25.87 | 4 |
| 8 | 40 | 117.26 | 31.42 | 5 |
| 8 | 48 | 130.38 | 36.77 | 6 |
| 8 | 56 | 142.3 | 41.95 | 7 |
| 8 | 64 | 153.3 | 46.99 | 8 |
| 8 | 72 | 163.55 | 51.9 | 9 |
| 8 | 80 | 173.21 | 56.7 | 10 |
| 8 | 88 | 182.35 | 61.39 | 11 |
| 8 | 96 | 191.05 | 65.98 | 12 |
| 8 | 104 | 199.37 | 70.49 | 13 |
| 8 | 112 | 207.36 | 74.91 | 14 |
| 8 | 120 | 215.06 | 79.26 | 15 |
| 8 | 128 | 222.49 | 83.54 | 16 |
| 8 | 136 | 229.67 | 87.74 | 17 |
| 8 | 144 | 236.64 | 91.89 | 18 |
| 8 | 152 | 243.41 | 95.97 | 19 |
| 8 | 160 | 250 | 100 | 20 |
| 8 | 168 | 256.42 | 103.97 | 21 |
| 8 | 176 | 262.68 | 107.9 | 22 |
| 8 | 184 | 268.79 | 111.77 | 23 |
| 8 | 192 | 274.77 | 115.59 | 24 |
| 8 | 200 | 280.62 | 119.38 | 25 |
| 8 | 208 | 286.36 | 123.11 | 26 |
| 8 | 216 | 291.98 | 126.81 | 27 |
| 8 | 224 | 297.49 | 130.47 | 28 |
| 8 | 232 | 302.9 | 134.09 | 29 |
| 8 | 240 | 308.22 | 137.67 | 30 |
| 8 | 256 | 318.59 | 144.73 | 32 |
| 8 | 272 | 328.63 | 151.65 | 34 |
| 8 | 288 | 338.38 | 158.46 | 36 |
| 8 | 304 | 347.85 | 165.14 | 38 |
| 8 | 320 | 357.07 | 171.71 | 40 |
| 8 | 336 | 366.06 | 178.18 | 42 |
| 8 | 352 | 374.83 | 184.56 | 44 |
| 8 | 368 | 383.41 | 190.83 | 46 |
| 8 | 384 | 391.79 | 197.02 | 48 |
| 8 | 400 | 400 | 203.13 | 50 |
| 8 | 440 | 419.82 | 218.04 | 55 |
| 8 | 480 | 438.75 | 232.49 | 60 |
| 8 | 520 | 456.89 | 246.53 | 65 |
| 8 | 560 | 474.34 | 260.2 | 70 |
| 8 | 600 | 491.17 | 273.52 | 75 |
| 8 | 640 | 507.44 | 286.52 | 80 |
| 8 | 680 | 523.21 | 299.23 | 85 |
| 8 | 720 | 538.52 | 311.66 | 90 |
| 8 | 760 | 553.4 | 323.84 | 95 |
| 8 | 800 | 567.89 | 335.78 | 100 |
| 8 | 1000 | 635.41 | 392.36 | 125 |
| 8 | 1200 | 696.42 | 444.63 | 150 |
| 8 | 1400 | 752.5 | 493.49 | 175 |
| 8 | 1600 | 804.67 | 539.57 | 200 |
| 8 | 1800 | 853.67 | 583.29 | 225 |
| 8 | 2000 | 900 | 625 | 250 |
| 8 | 2200 | 944.06 | 664.96 | 275 |
| 8 | 2400 | 986.15 | 703.38 | 300 |
| 9 | 9 | 40 | 8.37 | 1 |
| 9 | 18 | 75.5 | 15.6 | 2 |
| 9 | 27 | 98.99 | 22.4 | 3 |
| 9 | 36 | 117.9 | 28.88 | 4 |
| 9 | 45 | 134.16 | 35.09 | 5 |
| 9 | 54 | 148.66 | 41.09 | 6 |
| 9 | 63 | 161.86 | 46.91 | 7 |
| 9 | 72 | 174.07 | 52.56 | 8 |
| 9 | 81 | 185.47 | 58.07 | 9 |
| 9 | 90 | 196.21 | 63.45 | 10 |
| 9 | 99 | 206.4 | 68.71 | 11 |
| 9 | 108 | 216.1 | 73.86 | 12 |
| 9 | 117 | 225.39 | 78.92 | 13 |
| 9 | 126 | 234.31 | 83.88 | 14 |
| 9 | 135 | 242.9 | 88.76 | 15 |
| 9 | 144 | 251.2 | 93.55 | 16 |
| 9 | 153 | 259.23 | 98.28 | 17 |
| 9 | 162 | 267.02 | 102.93 | 18 |
| 9 | 171 | 274.59 | 107.51 | 19 |
| 9 | 180 | 281.96 | 112.03 | 20 |
| 9 | 189 | 289.14 | 116.49 | 21 |
| 9 | 198 | 296.14 | 120.89 | 22 |
| 9 | 207 | 302.99 | 125.23 | 23 |
| 9 | 216 | 309.68 | 129.53 | 24 |
| 9 | 225 | 316.23 | 133.77 | 25 |
| 9 | 234 | 322.65 | 137.97 | 26 |
| 9 | 243 | 328.94 | 142.12 | 27 |
| 9 | 252 | 335.11 | 146.22 | 28 |
| 9 | 261 | 341.17 | 150.28 | 29 |
| 9 | 270 | 347.13 | 154.3 | 30 |
| 9 | 288 | 358.75 | 162.23 | 32 |
| 9 | 306 | 370 | 170 | 34 |
| 9 | 324 | 380.92 | 177.63 | 36 |
| 9 | 342 | 391.54 | 185.14 | 38 |
| 9 | 360 | 401.87 | 192.52 | 40 |
| 9 | 378 | 411.95 | 199.78 | 42 |
| 9 | 396 | 421.78 | 206.93 | 44 |
| 9 | 414 | 431.39 | 213.98 | 46 |
| 9 | 432 | 440.79 | 220.93 | 48 |
| 9 | 450 | 450 | 227.78 | 50 |
| 9 | 495 | 472.23 | 244.52 | 55 |
| 9 | 540 | 493.46 | 260.74 | 60 |
| 9 | 585 | 513.81 | 276.51 | 65 |
| 9 | 630 | 533.39 | 291.85 | 70 |
| 9 | 675 | 552.27 | 306.8 | 75 |
| 9 | 720 | 570.53 | 321.4 | 80 |
| 9 | 765 | 588.22 | 335.67 | 85 |
| 9 | 810 | 605.39 | 349.63 | 90 |
| 9 | 855 | 622.09 | 363.31 | 95 |
| 9 | 900 | 638.36 | 376.71 | 100 |
| 9 | 1125 | 714.14 | 440.24 | 125 |
| 9 | 1350 | 782.62 | 498.94 | 150 |
| 9 | 1575 | 845.58 | 553.81 | 175 |
| 9 | 1800 | 904.16 | 605.54 | 200 |
| 9 | 2025 | 959.17 | 654.64 | 225 |
| 9 | 2250 | 1011.19 | 701.48 | 250 |
| 9 | 2475 | 1060.66 | 746.36 | 275 |
| 9 | 2700 | 1107.93 | 789.51 | 300 |
| 10 | 10 | 50.5 | 9.17 | 1 |
| 10 | 20 | 87.18 | 17.2 | 2 |
| 10 | 30 | 112.47 | 24.74 | 3 |
| 10 | 40 | 133.04 | 31.91 | 4 |
| 10 | 50 | 150.83 | 38.8 | 5 |
| 10 | 60 | 166.73 | 45.45 | 6 |
| 10 | 70 | 181.25 | 51.89 | 7 |
| 10 | 80 | 194.68 | 58.16 | 8 |
| 10 | 90 | 207.24 | 64.26 | 9 |
| 10 | 100 | 219.09 | 70.23 | 10 |
| 10 | 110 | 230.33 | 76.06 | 11 |
| 10 | 120 | 241.04 | 81.78 | 12 |
| 10 | 130 | 251.3 | 87.38 | 13 |
| 10 | 140 | 261.15 | 92.89 | 14 |
| 10 | 150 | 270.65 | 98.29 | 15 |
| 10 | 160 | 279.82 | 103.61 | 16 |
| 10 | 170 | 288.7 | 108.85 | 17 |
| 10 | 180 | 297.32 | 114.01 | 18 |
| 10 | 190 | 305.7 | 119.09 | 19 |
| 10 | 200 | 313.85 | 124.1 | 20 |
| 10 | 210 | 321.79 | 129.05 | 21 |
| 10 | 220 | 329.55 | 133.93 | 22 |
| 10 | 230 | 337.12 | 138.75 | 23 |
| 10 | 240 | 344.53 | 143.51 | 24 |
| 10 | 250 | 351.78 | 148.22 | 25 |
| 10 | 260 | 358.89 | 152.87 | 26 |
| 10 | 270 | 365.86 | 157.47 | 27 |
| 10 | 280 | 372.69 | 162.03 | 28 |
| 10 | 290 | 379.41 | 166.53 | 29 |
| 10 | 300 | 386.01 | 170.99 | 30 |
| 10 | 320 | 398.87 | 179.78 | 32 |
| 10 | 340 | 411.34 | 188.4 | 34 |
| 10 | 360 | 423.44 | 196.87 | 36 |
| 10 | 380 | 435.2 | 205.2 | 38 |
| 10 | 400 | 446.65 | 213.38 | 40 |
| 10 | 420 | 457.82 | 221.44 | 42 |
| 10 | 440 | 468.72 | 229.37 | 44 |
| 10 | 460 | 479.37 | 237.19 | 46 |
| 10 | 480 | 489.8 | 244.9 | 48 |
| 10 | 500 | 500 | 252.5 | 50 |
| 10 | 550 | 524.64 | 271.07 | 55 |
| 10 | 600 | 548.18 | 289.07 | 60 |
| 10 | 650 | 570.75 | 306.56 | 65 |
| 10 | 700 | 592.45 | 323.58 | 70 |
| 10 | 750 | 613.39 | 340.18 | 75 |
| 10 | 800 | 633.64 | 356.37 | 80 |
| 10 | 850 | 653.26 | 372.21 | 85 |
| 10 | 900 | 672.31 | 387.7 | 90 |
| 10 | 950 | 690.83 | 402.87 | 95 |
| 10 | 1000 | 708.87 | 417.74 | 100 |
| 10 | 1250 | 792.94 | 488.23 | 125 |
| 10 | 1500 | 868.91 | 553.36 | 150 |
| 10 | 1750 | 938.75 | 614.25 | 175 |
| 10 | 2000 | 1003.74 | 671.66 | 200 |
| 10 | 2250 | 1064.78 | 726.14 | 225 |
| 10 | 2500 | 1122.5 | 778.12 | 250 |
| 10 | 2750 | 1177.39 | 827.92 | 275 |
| 10 | 3000 | 1229.84 | 875.8 | 300 |

# SYSTEMIZING RF POWER AMPLIFIER DESIGN

Prepared by:
**Roy Hejhall**

## INTRODUCTION

Two of the most popular RF small signal design techniques are:

1) the use of two port parameters, and
2) the use of some type of equivalent circuit for the transistor.

Early attempts to adapt these techniques to power amplifier design led to poor results and frustration.

In the mid-1960's, Motorola pioneered the concept of solid state power amplifier design through the use of large signal transistor input and output impedances. This system has since achieved almost universal acceptance by solid state communications equipment manufacturers. It provides a systematic design procedure to replace what used to be a trial and error process. This note is a description of the concept and its use in transmitter design.

## LIMITATIONS OF SMALL-SIGNAL PARAMETERS

As a vivid example to show the short-comings of trying to adapt small-signal parameters to power amplifier design, the 2N3948 transistor was considered. A performance comparison was made of the 2N3948 operating at 300 MHz as a Class A small-signal amplifier, and as a Class C* power amplifier delivering a power output of 1 W. Table I shows the results of this comparison.

| | CLASS A Small-signal amplifier $V_{CE}$ = 15 Vdc; $I_C$ = 80 mA; 300 MHz | CLASS C Power amplifier $V_{CE}$ = 13.6 Vdc; $P_o$ = 1 W |
|---|---|---|
| Input resistance | 9 Ohms | 38 Ohms |
| Input capacitance or inductance | 0.012 μH | 21 pF |
| Transistor output resistance | 199 Ohms | 92 Ohms |
| Output capacitance | 4.6 pF | 5.0 pF |
| $G_{PE}$ | 12.4 dB | 8.2 dB |

Table I — Small- and large-signal performance data for the 2N3948 show the inadequacy of using small-signal characterization data for large-signal amplifier design. Resistances and reactances shown are parallel components. That is, the large-signal input impedance is 38 ohms in parallel with 21 pF, etc.

The most striking difference in this comparison is in the device input impedance. As operation is changed from small-signal to large-signal conditions, the complex input impedance of the 2N3948 undergoes a considerable change in magnitude and actually changes from inductive to capacitive reactance.

Note also that the transistor's output resistances and power gains are considerably different for the two modes of operation. This example clearly demonstrates the inaccuracies that would result in a power-amplifier design based on the small-signal parameters of this device.

## IMPORTANCE OF LARGE-SIGNAL PARAMETERS

The network theory for power amplifier design is well known but is useless unless the designer has valid input and output impedance data for the transistor. The design method described in this report hinges primarily on the direct measurement of these parameters for use in network synthesis equations. Large-signal impedance data, together with power output and gain data, provide the designer with the information necessary to design his amplifier networks and to predict the performance that should be achieved when the design is completed.

A clear understanding of the test conditions and method of presentation for the large signal impedance data is important.

## TEST CONDITIONS

The term "large-signal input impedance" and "large-signal output impedance" refer to the actual transistor terminal impedances when operating in a matched amplifier at the desired RF power output level and dc supply voltage.

"Matched" is defined as the condition where the input and output networks of the test amplifier provide a conjugate match to the transistor, such that the input and output impedances of the amplifier are 50 + j 0 ohms.

Large-signal impedances should not be confused with small-signal, two port parameters which are normally measured at low signal levels with Class A bias and the transistor (or IC) connected directly to a short, open, or 50 ohm termination.

Most of the data which appears on Motorola RF power transistor data sheets is measured in common emitter, Class C amplifiers; as this condition covers the majority of device applications.

One significant exception to this involves transistors characterized for Class B linear power amplifier service. Examples of such transistors are the Motorola 2N5941-2 series. Since these transistors are designed specifically for linear service, their large-signal impedances were measured in a linear power amplifier test circuit with a two tone test signal instead of the conventional single frequency signal. For further information on these transistors see the

*Class C, as used here, refers to operation with both the emitter and base at dc ground potential and with the collector supply as the only dc voltage applied, regardless of resulting device conduction angle. Usually, the emitter is connected directly to chassis ground and the base is dc grounded through an inductive network element or choke.

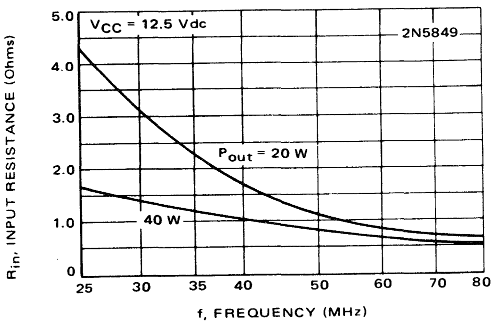



**FIGURE 1 – Parallel Equivalent Input Resistance versus Frequency**

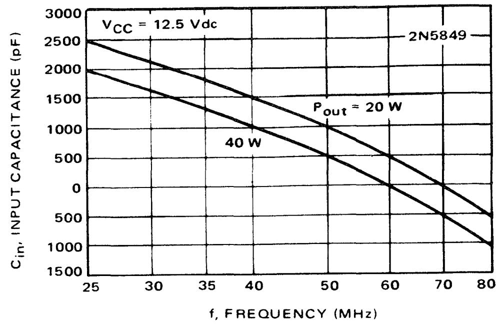



**FIGURE 2 – Parallel Equivalent Input Capacitance versus Frequency**

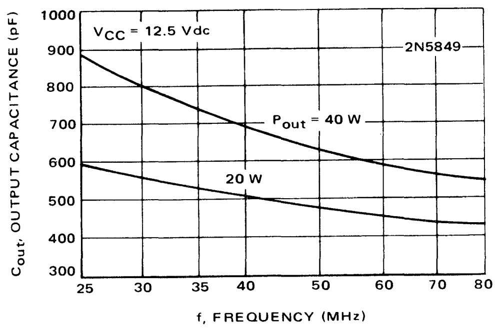



**FIGURE 3 – Parallel Equivalent Output Capacitance versus Frequency**

Motorola 2N5941-2 data sheet.

## DATA FORMAT

Much of the information on device data sheets is presented in parallel equivalent form of resistance and capacitance. Figures 1-3 form an example of this type of presentation. The data may also be presented in series equivalent form. It makes no difference which form is used as long as the designer pays particular attention to the form and uses the data accordingly. As a convenience, the series-parallel equivalent conversion equations are given in Appendix A.

For example, reading the complex input impedance, from Figures 1 and 2 at 50 MHz with 40 W output and a 12.5 Vdc collector supply, we obtain a value of 0.8 ohms resistance in parallel with a 500 pF capacitance.

Another form of impedance data presentation uses the series equivalent form plotted on a Smith Chart. This form is popular with UHF power transistors due to the extensive use of the Smith Chart in microstrip network synthesis. Figure 4 is an example of large-signal impedances plotted on a Smith Chart plot. Note that Figure 4 includes complete complex output impedance data, not just the output capacitance. This topic is discussed more fully in the section on collector load resistance.

## AMPLIFIER DESIGN

After selection of a transistor with the required performance capabilities, the next step in the design of a power amplifier is to determine the large-signal input and output impedances of the transistor. When using devices for which the data is available, this step involves nothing more than reading the complex impedance values off of the data sheet. If only output capacitance is given on the data sheet, the collector load resistance may be calculated in the manner described in the Collector Load Resistance Section of this note.

Again, the designer is cautioned to carefully determine whether the data sheet impedance curves are in parallel or series equivalent form, and to use the data accordingly. If the data is not available, a later section of this note contains information on large-signal impedance measurement.

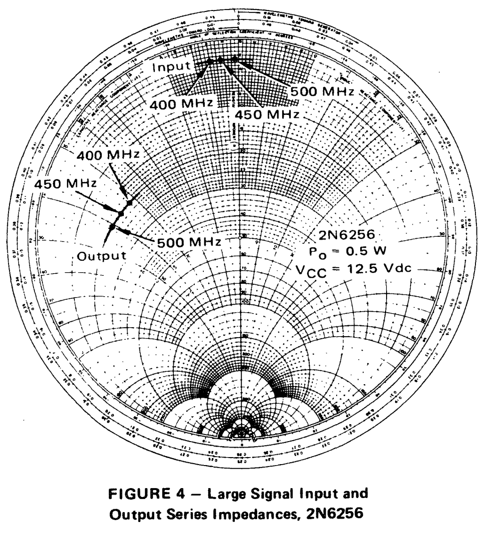



**FIGURE 4 – Large Signal Input and Output Series Impedances, 2N6256**

Having determined the large-signal impedances, the designer selects a suitable network configuration and proceeds with his network synthesis.

The primary purpose of this note is to describe the large-signal impedance concept. Accordingly, network selection and synthesis are beyond the scope of this discussion. For specific transmitter design examples using this concept, the reader is referred to the following Motorola Application Note: AN-548A.

## COLLECTOR LOAD RESISTANCE

Large-signal impedance data at HF and VHF have for the most part been published by Motorola without collector load resistance information. The reason is that the load resistance can easily be calculated. The conditions necessary to obtain this load resistance derivation will now be discussed.

If certain simplifying assumptions are made, the theoretical collector voltage of a power amplifier with a tuned output network is a sine wave which swings from zero to 2 $V_{CC}$, where $V_{CC}$ is the dc collector supply voltage. These assumptions include:

1. $V_{CE(sat)}$ is equal to zero.
2. The output network has sufficient loaded Q to produce a sine wave voltage regardless of transistor conduction angle.
3. The voltage drop in the dc collector supply feed system is zero.
4. The collector load impedance at all harmonics of the operating frequency is zero.

Obviously none of the foregoing assumptions is true, and the most serious discrepancies probably arise from assumptions 1 and 4. However, conditions are close enough to give good results.

Let us assume for a moment that this theoretical condition does exist. The parallel equivalent collector load resistance, $R_L'$, then becomes a function of desired RF output power and $V_{CC}$ only. The expression for $R_L'$ given in equation 1 is readily derived.

$$R_L' = \frac{(V_{CC})^2}{2P} \qquad (1)$$

where P = RF output power

Therefore, the complex collector load impedance for an amplifier design would be the conjugate of the parallel equivalent output capacitance and collector load resistance computed with Equation 1.

Figure 5 provides a graphic solution to Equation 1 for the four popular dc supply levels of 12.5, 13.6, 24 and 28 volts.

Despite the assumptions required, experience with HF and VHF lumped-component, power amplifiers with supply voltages from 7 to 30 Vdc and power output levels from a few tenths of a watt to 300 watts have proven that the use of Equation 1 to compute $R_L'$ for network synthesis yields good results. That is to say, the types of HF and VHF lumped component collector output networks which

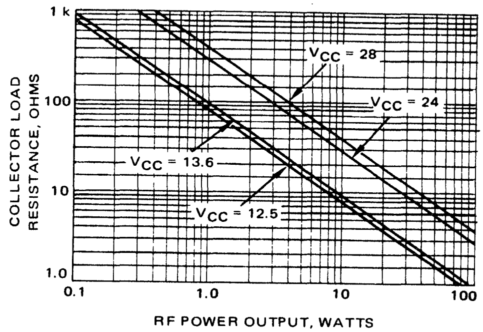



**FIGURE 5 — Collector Load Resistance versus Power Output**

have proved best from the standpoint of proper impedance matching with low losses and smooth tuning generally have a sufficient tuning and matching range to compensate for any errors associated with Equation 1.

Of course if the $V_{CE(sat)}$ of the transistor is accurately known for the frequency of operation and collector current swings anticipated in a particular amplifier, Equation 1 is readily modified as follows:

$$R_L' = \frac{(V_{CC}-V_{CE(sat)})^2}{2P} \qquad (2)$$

The advent of greatly increased numbers of UHF power transistors and their associated amplifier design problems brought some revisions to Motorola's methods of presenting large-signal transistor impedances for UHF devices. Among the reasons for this are the popularity of microstrip matching networks and the higher $V_{CE(sat)}$ values at UHF.

The major difference in the data format involves output impedance, which is presented in full complex form instead of plotting parallel equivalent output capacitance only and using Equation 1 to compute the load resistance. Further, the UHF devices are measured in a microstrip test amplifier for the purpose of determining the transistor impedances in an environment which is as close as possible to that of the majority of the actual applications of the device. And finally, a Smith Chart plot is used as this is more convenient to the microstrip network designer, who often makes extensive use of the Smith Chart as a design tool.

Future Motorola data sheets may also include collector load resistance data at frequencies below UHF. The information is automatically generated for the test circuit in use while measuring $C_{in}$, $R_{in}$ and $C_{out}$.

## PARAMETER MEASUREMENT

Although design engineers will find large-signal impedance characterization on Motorola data sheets for RF power transistors, it may help to know how this data is obtained. The transistor is placed in a test circuit designed to provide wide tuning capabilities. Design of the first

test amplifier for a new transistor type is based on estimates of input and output impedance.

Since the input and output impedances are needed to design an amplifier which is then used to measure the impedances of the device, we have a "chicken or the egg" type of problem. Wide tuning range networks help compensate for errors in the impedance estimates and they also permit the same characterization amplifier to be used at multiple power output levels.

The amplifier is tuned for a careful impedance match at both input and output. Several precautions are in order to insure that this is accomplished.

Tuning for maximum power output is valid only if the source and load impedances are an accurate 50 + j 0 ohms. Usually a good 50 ohm load is available in the laboratory. Such a load should be used, as tuning for maximum output power for a given input power is the best method to use on the amplifier output network.

The input network poses some additional problems. First, many laboratory RF power sources are not accurate 50 ohm generators. A generator impedance that is not 50 ohms can introduce errors in measuring gain as well as input impedances. In addition, a source with high harmonic levels can cause difficulties in low Q input networks.

A good solution to this problem is to use a dual directional coupler or directional power meter in the coax line between the generator and the test amplifier. The amplifier is then tuned for zero reflected power, thus indicating that the input network is really matching the transistor input impedance to 50 + j 0 ohms.

In practice, the reflected power usually will not null all the way to zero, so one should insure that the null is at least as deep as that obtained with a good 50 ohm passive termination.

In some cases, the amplifier will reflect enough harmonic power to prevent a satisfactory reflected power null from being obtained. A good solution to this problem is to place a fundamental frequency bandpass filter at the reflected power port of the dual directional coupler.

A typical test amplifier for HF and VHF measurements is shown in Figure 6. For UHF device characterization, amplifiers employing microstrip matching networks are most commonly employed.

After the test amplifier has been properly tuned, the dc power, signal source, circuit load, and test transistor are disconnected from the circuit. Then the signal source and output load circuit connections are each terminated with 50 ohms. After performing these substitutions, complex impedances are measured at the base and collector circuit connections of the test transistor (points A and B respectively in Figure 7). The desired data, the transistor input and output impedances, will be the conjugates of the base circuit connection and the collector circuit connection, impedances respectively.

By operating test amplifiers at several different frequencies with at least two power outputs, sufficient data can be obtained to characterize a transistor for the majority of its power applications.

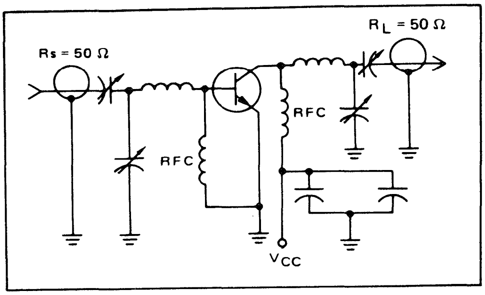
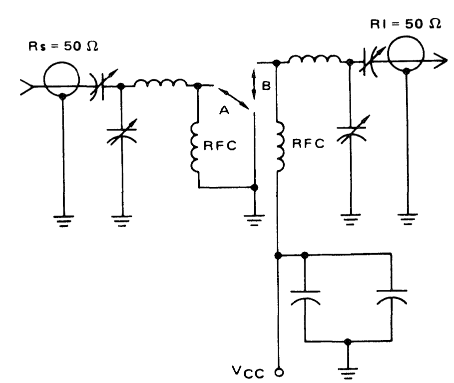



FIGURE 6 – Typical Test Amplifier Circuit




Complex impedances are measured at the base and collector circuit connections of the test transistor (points A and B respectively). Desired data will be the conjugates of these impedances.

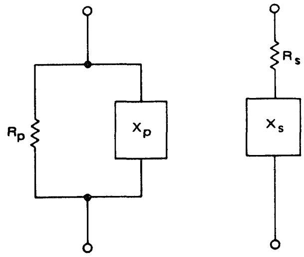
FIGURE 7 – Test Circuit with Transistor Removed

## SUMMARY

The large-signal impedance characterization of RF power transistors has provided the most systematic and successful power amplifier design method the author has encountered since the concept was explored in depth in the mid 1960's.

## APPENDIX A

PARALLEL-TO-SERIES AND SERIES-TO-PARALLEL IMPEDANCE CONVERSION EQUATIONS.




$$R_p = R_s\left[1 + \left(\frac{X_s}{R_s}\right)^2\right]$$

$$X_p = \frac{R_p \cdot R_s}{X_s}$$

$$R_s = \frac{R_p}{1 + \left(\frac{R_p}{X_p}\right)^2}$$

$$X_s = \frac{R_s \cdot R_p}{X_p}$$

# IMPEDANCE MATCHING NETWORKS APPLIED TO RF POWER TRANSISTORS

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## 1. INTRODUCTION

Some graphic and numerical methods of impedance matching will be reviewed here. The examples given will refer to high frequency power amplifiers.

Although matching networks normally take the form of filters and therefore are also useful to provide frequency discrimination, this aspect will only be considered as a corollary of the matching circuit.

Matching is necessary for the best possible energy transfer from stage to stage. In RF-power transistors the input impedance is of low value, decreasing as the power increases, or as the chip size becomes larger. This impedance must be matched either to a generator — of generally 50 ohms internal impedance — or to a preceding stage. Impedance transformation ratios of 10 or even 20 are not rare. Interstage matching has to be made between two complex impedances, which makes the design still more difficult, especially if matching must be accomplished over a wide frequency band.

## 2. DEVICE PARAMETERS

### 2.1 INPUT IMPEDANCE

The general shape of the input impedance of RF-power transistors is as shown in Figure 1. It is a large signal parameter, expressed here by the parallel combination of a resistance $R_p$ and a reactance $X_p$ (Ref. (1)).

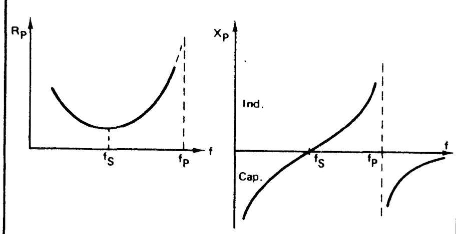
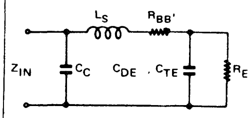



*Fig. 1 — Input impedance of RF-power transistors as a function of frequency*

The equivalent circuit shown in Figure 2 accounts for the behaviour illustrated in Figure 1.

With the presently used stripline or flange packaging, most of the power devices for VHF low band will have their $R_p$ and $X_p$ values below the series resonant point fs. The input impedance will be essentially capacitive.




Where:
$R_E$ = emitter diffusion resistance
$C_{DE}$ , $C_{TE}$ = diffusion and transition capacitances of the emitter junction
$R_{BB'}$ = base spreading resistance
$C_C$ = package capacitance
$L_S$ = base lead inductance

*Fig. 2 — Equivalent circuit for the input impedance of RF-power transistors*

Most of the VHF high band transistors will have the series resonant frequency within their operating range, i.e. be purely resistive at one single frequency $f_S$, while the parallel resonant frequency $f_p$ will be outside.

Parameters for one or two gigahertz transistors will be beyond $f_S$ and approach $f_p$. They show a high value of $R_p$ and $X_p$ with inductive character.

A parameter that is very often used to judge on the broadband capabilities of a device is the input Q or $Q_{IN}$, defined simply as the ratio $R_p/X_p$. Practically $Q_{IN}$ ranges around 1 or less for VHF devices and around 5 or more for microwave transistors.

$Q_{IN}$ is an important parameter to consider for broadband matching. Matching networks normally are low-pass or pseudo low-pass filters. If $Q_{IN}$ is high, it can be necessary to use band-pass filter type matching networks and to allow insertion losses. But broadband matching is still possible. This will be discussed later.

### 2.2. OUTPUT IMPEDANCE

The output impedance of the RF-power transistors, as given by all manufacturers' data sheets, generally consists of only a capacitance $C_{OUT}$. The internal resistance of the transistor is supposed to be much higher than the load and is normally neglected. In the case of a relatively low internal resistance, the efficiency of the device would decrease by the factor:

$$1 + R_L/R_T$$

where $R_L$ is the load resistance, seen at the collector-emitter terminals, and $R_T$ the internal transistor resistance equal to:

$$\frac{1}{\omega_T \cdot (C_{TC} + C_{DC})},$$

defined as a small signal parameter, where:

$\omega_T$ = transit angular frequency

$C_{TC} + C_{DC}$ = transition and diffusion capacitances at the collector junction

The output capacitance $C_{OUT}$, which is a large signal parameter, is related to the small signal parameter $C_{CB}$, the collector-base transistion capacitance.

Since a junction capacitance varies with the applied voltage, $C_{OUT}$ differs from $C_{CB}$ in that it has to be averaged over the total voltage swing. For an abrupt junction and assuming certain simplifications, $C_{OUT} = 2\ C_{CB}$.

Figure 3 shows the variation of $C_{OUT}$ with frequency. $C_{OUT}$ decreases partly due to the presence of the collector lead inductance, but mainly because of the fact that the base-emitter diode does not shut off anymore when the operating frequency approaches the transit frequency $f_T$.

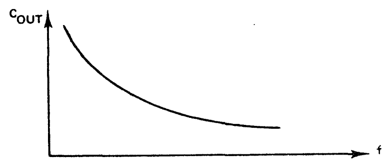



*Fig. 3 – Output capacitance $C_{OUT}$ as a function of frequency*

## 3. OUTPUT LOAD

In the absence of a more precise indication, the output load $R_L$ is taken equal to:

$$R_L = \frac{[V_{CC} - V_{CE\,(sat)}]^2}{2\,P_{OUT}}$$

with $V_{CE\,(sat)}$ equal to 2 or 3 volts, increasing with frequency.

The above equation just expresses a well-known relation, but also shows that the load, in first approximation, is not related to the device, except for $V_{CE\,(sat)}$. The load value is primarily dictated by the required output power and the peak voltage; it is not matched to the output impedance of the device.

At higher frequencies this approximation becomes less exact and for microwave devices the load that must be presented to the device is indicated on the data sheet. This parameter will be measured on all Motorola RF-power devices in the future.

Strictly speaking, impedance matching is accomplished only at the input. Interstage and load matching are more impedance transformations of the device input impedance and of the load into a value $R_L$ (sometimes with additional reactive component) that depends essentially on the power demanded and the supply voltage.

## 4. MATCHING NETWORKS

In the following, matching networks will be described by order of complexity. These are ladder type reactance networks.

The different reactance values will be calculated and determined graphically. Increasing the number of reactances broadens the bandwidth. However, networks consisting of more than four reactances are rare. Above four reactances, the improvement is small.

### 4.1 NUMERICAL DESIGN

#### 4.1.1 Two-Resistance Networks

Resistance terminations will first be considered. Figure 4 shows the reactive L-section and the terminations to be matched.

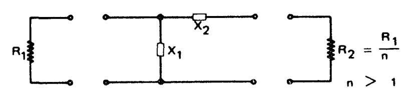



*Fig. 4 – Two-Reactance Matching Network*

Matching or exact transformation from $R_2$ into $R_1$ occurs at a single frequency $f_o$.

At $f_o$, $X_1$ and $X_2$ are equal to:

$$X_1 = \pm R_1 \sqrt{\frac{R_2}{R_1 - R_2}} = R_1 \frac{1}{\sqrt{n-1}}$$

$$X_2 = \mp \sqrt{R_2\,(R_1 - R_2)} = R_1 \frac{\sqrt{n-1}}{n}$$

At $f_o$: $X_1 \cdot X_2 = R_1 \cdot R_2$

$X_1$ and $X_2$ must be of opposite sign. The shunt reactance is in parallel with the larger resistance.

The frequency response of the L-section is shown in Figure 5, where the normalized current is plotted as a function of the normalized frequency.

If $X_1$ is capacitive and consequently $X_2$ inductive, then:

$$X_1 = -\frac{fo}{f} R_1 \sqrt{\frac{R_2}{R_1 - R_2}} = -\frac{fo}{f} R_1 \frac{1}{\sqrt{n-1}}$$

and $$X_2 = \frac{f}{fo} \sqrt{R_2\,(R_1 - R_2)} = \frac{f}{fo} R_1 \frac{\sqrt{n-1}}{n}$$

The normalized current absolute value is equal to:

$$\left|\frac{I_2}{I_0}\right| = \frac{2\sqrt{n}}{\sqrt{(n-1)^2 \cdot \left(\frac{f}{f_0}\right)^4 - 2\left(\frac{f}{f_0}\right)^2 + (n+1)^2}}$$

where $I_0 = \frac{\sqrt{n}\,E}{2.R_1}$, and is plotted in Figure 5 (Ref. (2) ).

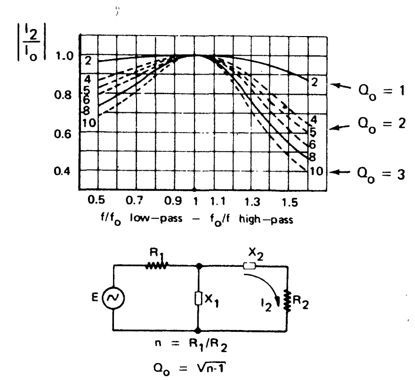



*Fig. 5 – Normalized frequency response for the L–section in low–pass or high–pass form*

If $X_1$ is inductive and consequently $X_2$ capacitive, the only change required is a repacement of f by $f_0$ and vice-versa. The L-section has low pass form in the first case and high-pass form in the second case.

The Q of the circuit at $f_0$ is equal to:

$$Q_0 = \frac{X_2}{R_2} = \frac{R_1}{X_1} = \sqrt{n-1}$$

For a given transformation ratio n, there is only one possible value of Q. On the other hand, there are two symmetrical solutions for the network, that can be either a low-pass filter or a high-pass filter.

The frequency $f_0$ does not need to be the center frequency, $\frac{f_1 + f_2}{2}$, of the desired band limited by $f_1$ and $f_2$.

In fact, as can be seen from the low-pass configuration of Figure 5, it may be interesting to shift fo toward the high band edge frequency $f_2$ to obtain a larger bandwidth w, where $w = \frac{2(f_1 + f_2)}{f_2 - f_1}$

This will, however, be at the expense of poorer harmonic rejection.

Example:

For a transformation ratio n = 4, it can be determined from the above relations:

| | | |
|---|---|---|
| Bandwidth w | 0.1 | 0.3 |
| Max insertion losses | 0.025 | 0.2 |
| $X_1/R_1$ | 1.730 | 1.712 |

If the terminations $R_1$ and $R_2$ have a reactive component X, the latter may be taken as part of the external reactance as shown in Figure 6.

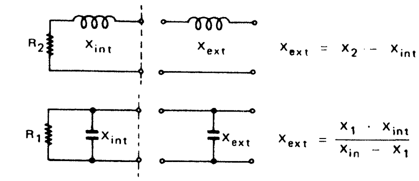



*Fig. 6 – Termination Reactance Compensation*

This compensation is applicable as long as

$$Q_{INT} = \frac{X_{INT}}{R_2} \text{ or } \frac{R_1}{X_{INT}} < n-1$$

Tables giving reactance values can be found in Ref. (3) and (4).

### 4.1.1.1 Use of transmission lines and inductors

In the preceding section, the inductance was expected to be realized by a lumped element. A transmission line can be used instead (Fig 7).

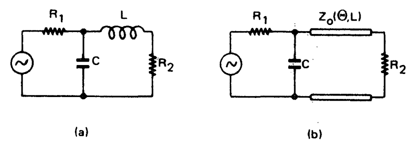



*Fig. 7 – Use of a transmission line in the L–section*

As can be seen from the computed selectivity curves (Fig. 8) for the two configurations, transmission lines result in a larger bandwidth. The gain is important for a transmission line having a length $L = \lambda/4$ ($\Theta = 90°$) and a characteristic impedance $Z_0 = \sqrt{R_1 \cdot R_2}$. It is not significant for lines short with respect to $\lambda/4$. One will notice that there is an infinity of solutions, one for each value of C, when using transmission lines.

### 4.1.2 Three-reactance matching networks

The networks which will be investigated are shown in Figure 9. They are made of three reactances alternatively connected in series and shunt.

A three-reactances configuration allows to make the quality factor Q of the circuit and the transformation ratio $n = \frac{R_2}{R_1}$ independent of each other and consequently to choose the selectivity between certain limits.

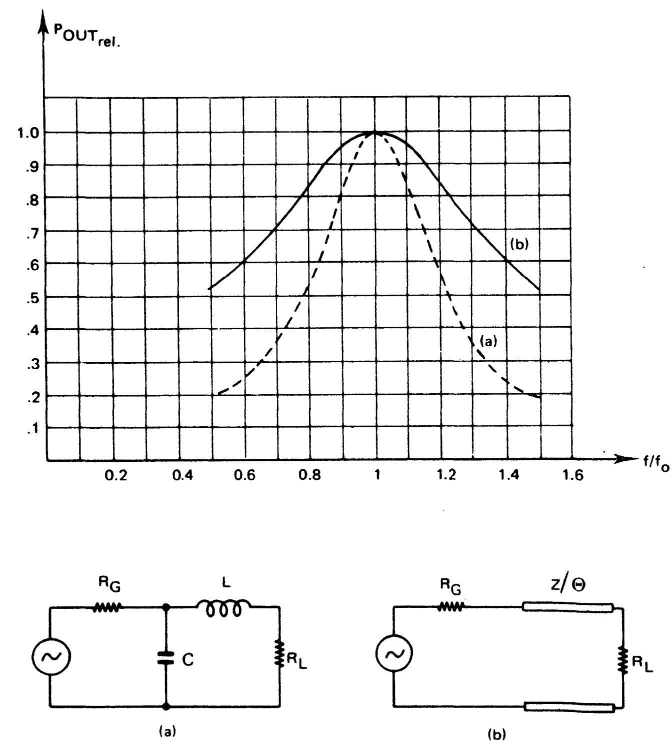
For narrow band designs, one can use the following formulas (Ref. (5) AN-267, where tables are given):

Network (a):

$$X_{C1} = R_1/Q \quad \text{Q must be first selected}$$

$$X_{C2} = R_2 \sqrt{\frac{R_1 R_2}{(Q^2+1) - \frac{R_1}{R_2}}}$$

$$X_L = \frac{QR_1 + (R_1 R_2/X_{C2})}{Q^2 + 1}$$




Transformation ratio n = 10

*Fig. 8 – Bandwidth of the L–section for n = 10*
*(a) with lumped constants*
*(b) with a transmission line (λ/4)*

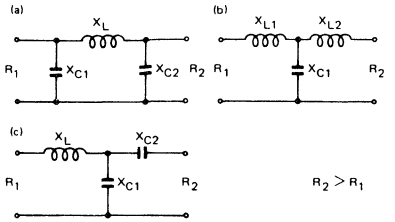



*Fig. 9 – Three–reactance matching networks*

Network (b) : Q must first be selected

$$X_{L1} = R_1 Q$$

$$X_{L2} = R_2 . B \qquad A = R_1 \; (1 + Q^2)$$

$$X_{C1} = \frac{A}{Q + B} \qquad B = \sqrt{\frac{A}{R_2} - 1}$$

Network (c) : Q must first be selected

$$X_{L1} = Q . R_1$$

$$X_{C2} = A . R_2 \qquad A = \sqrt{\frac{R_1 \; (1+Q^2)}{R_2} - 1}$$

$$X_{C1} = \frac{B}{Q - A} \qquad B = R_1 . (1 + Q^2)$$

The network which yields the most practical component values, should be selected for a given application.

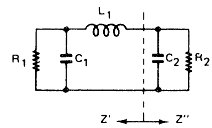
The three-reactance networks can be thought of as being formed of a L-section (two reactances) and of a compensation reactance. The L-section essentially performs the impedance transformation, while the additional reactance compensates for the reactive part of the transformed impedance over a certain frequency band.

Figure 10 shows a representation in the Z-plane of the circuit of Figure 9 (a) split into two parts $R_1$-$C_1$-$L_1$ and $C_2$-$R_2$.

Exact transformation from $R_1$ into $R_2$ occurs at the points of intersection M and N. Impedances are then conjugate or $Z' = R' + jX'$ and $Z'' = R'' + jX''$ with $R' = R''$ and $X' = -X''$.

The only possible solution is obtained when X' and -X'' are tangential to each other. For the dashed curve, representing another value of $L_1$ or $C_1$, a wider frequency band could be expected at the expense of some ripple inside the band. However, this can only be reached with four reactances as will be shown in section 4.1.3.

With a three-reactance configuration, there are not enough degrees of freedom to permit $X' = -X''$ and simultaneously obtain the same variation of frequency on both curves from M' to point N'.




$$Z' = \frac{R_1}{1 + \omega^2 R_1^2 C_1^2} + j\omega \left[ L_1 - \frac{R_1^2 C_1}{1 + \omega^2 R_1^2 C_1^2} \right] = R' + jX'$$

$$Z'' = \frac{R_2}{1 + \omega^2 C_2^2 R_2^2} - \frac{j\omega C_2 R_2^2}{1 + \omega^2 C_2^2 R_2^2} = R'' + jX''$$

$$|X'| = \left( \frac{L_1}{C_1 R_1^2} - \frac{R'}{R_1} \right) \sqrt{\frac{R_1}{R'} - 1}$$

$$|X''| = \sqrt{R' R_2 - R'^2}$$

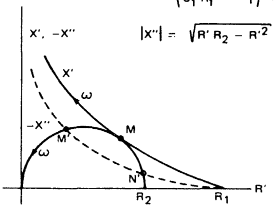



*Fig. 10 – Z–plane representation of the circuit of Fig. 9 (a)*

Exact transformation can, therefore, only be obtained at one frequency.

The values of the three reactances can be calculated by making $X' = -X''$, $R' = R''$ and $\frac{dX'}{dR'} = -\frac{dX''}{dR''}$.

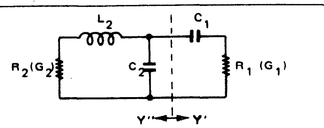
The general solution of these equations leads to complicated calculations. Therefore, computed tables should be used.

One will note on Figure 10 that the compensation reactance contributes somewhat to impedance transformation, i.e. R' varies when going from M to $R_2$.

The circuit of Figure 9 (b) is dual with respect to the first one and gives exactly the same results in a Y-plane representation.

Circuit of Figure 9 (c) is somewhat different since only one intersection M exists as shown in Figure 11. Narrower frequency bands must be expected from this configuration. The widest band is obtained for $C_1 = \infty$

Again, if one of the terminations has a reactive component, the latter can be taken as a part of the matching network, provided it is not too large (see Fig. 6).




$$Y' = G' + jB' = \frac{\omega^2 C_1^2 R_1}{1+\omega^2 C_1^2 R_1^2} - \frac{j\omega C_1}{1+\omega^2 C_1^2 R_1^2}$$

$$Y'' = G'' + jB'' = \frac{R_2}{R_2^2+\omega^2 L_2^2} + j\omega C_2 - \frac{j\omega L_2}{R_2^2+\omega^2 L_2^2}$$

$$B' = -\sqrt{G'/R_1 - G'^2} \qquad B'' = (1/kR_2 - G'')\sqrt{1/G''R_2 - 1}$$

$$k = L_2 / C_2 R_2^2$$

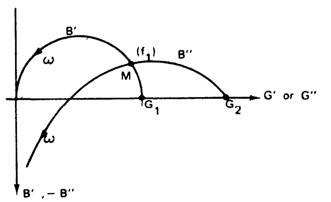



*Fig. 11 – Y-plane representation of the circuit of fig. 9 (c)*

### 4.1.3 Four-reactance networks

Four-reactance networks are used essentially for broadband matching. The networks which will be considered in the following consist of two two-reactance sections in cascade. Some networks have pseudo low-pass filter character, others band-pass filter character. In principle, the former show narrower bandwidth since they extend the impedance transformation to very low frequencies unnecessarily, while the latter insure good matching over a wide frequency band around the center frequency only (see Fig. 14).

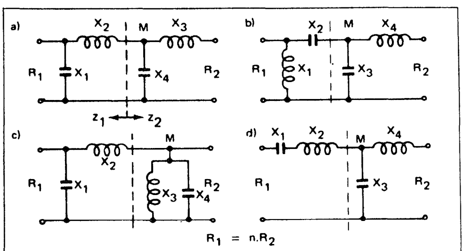



*Fig. 12 – Four-reactance networks*

The two-reactance sections used in above networks have either transformation properties or compensation properties. Impedance transformation is obtained with one series reactance and one shunt reactance. Compensation is made with both reactances in series or in shunt.

If two cascaded transformation networks are used, transformation is accomplished partly by each one.

With four-reactance networks there are two frequencies. $f_1$ and $f_2$, at which the transformation from $R_1$ into $R_2$ is exact. These frequencies may also coincide.

For network (b) for instance, at point M, $R_1$ or $R_2$ is transformed into $\sqrt{R_1 R_2}$ when both frequencies fall together. At all points (M), $Z_1$ and $Z_2$ are conjugate if the transformation is exact.

In the case of Figure 12 (b) the reactances are easily calculated for equal frequencies:

$$X_1 = \frac{R_1}{\sqrt{\sqrt{n}-1}}, \quad X_2 = R_1\sqrt{\frac{\sqrt{n}-1}{n}} \qquad X_1 . X_4 = R_1 . R_2 = X_2 . X_3$$

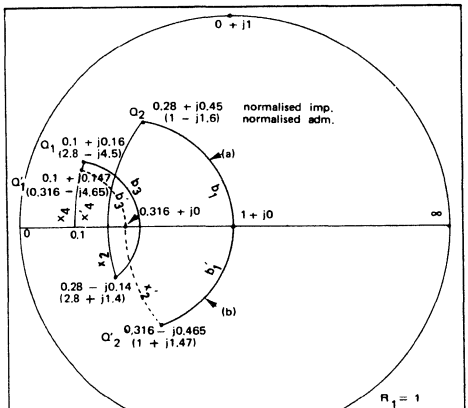
$$X_3 = \frac{R_1}{\sqrt{n}\,(\sqrt{n}-1)}, \quad X_4 = \frac{R_1}{n}\sqrt{\sqrt{n}-1}$$

For network (a) normally, at point (M), $Z_1$ and $Z_2$ are complex. This pseudo low-pass filter has been computed elsewhere (Ref. (3)). Many tables can be found in the literature for networks of four and more reactances having Tchebyscheff character or maximally-flat response (Ref. (3), (4) and (6)).

Figure 13 shows the transformation path from $R_1$ to $R_2$ for networks (a) and (b) on a Smith-Chart (refer also to section 4.2, Graphic Design).

Case (a) has been calculated using tables mentioned in Ref. (4).

Case (b) has been obtained from the relationship given above for $X_1$ . . . $X_4$. Both apply to a transformation ratio equal to 10 and for $R_1$ = 1.




| | | | |
|---|---|---|---|
| (a) $X_1 = 0.624$ | $X_3 = 0.169$ | (b) $X'_1 = 0.68$ | $X'_3 = 0.215$ |
| $B_1 = 1.6$ | $B_3 = 5.9$ | $B'_1 = 1.47$ | $B'_3 = 4.65$ |
| $X_2 = 0.59$ | $X_4 = 0.160$ | $X'_2 = 0.465$ | $X'_4 = 0.147$ |
| $Q_1 = 1.6 = Q_2$ | | $Q'_1 = Q'_2 = 1.47$ | |

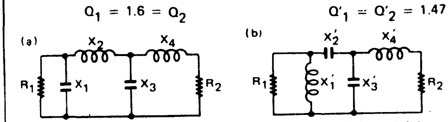



*Fig. 13 – Transformation paths for networks (a) and (b)*

There is no simple relationship for $X'_1 \ldots X'_4$ of network (b) if $f_1$ is made different from $f_2$ for larger bandwidth.

Figure 14 shows the respective bandwidths of network (a) and (b) for the circuits shown in Figure 13.

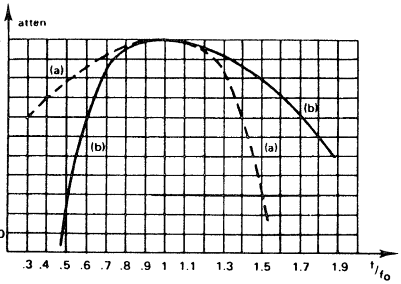



*Fig. 14 – Selectivity curves for networks (a) and (b) of Fig. 13*

If the terminations contain a reactive component, the computed values for $X_1$ or $X_4$ may be adjusted to compensate for this.

For configuration (a), it can be seen from Figure 13, that in the considered case the Q's are equal to 1.6.

For configuration (b) $Q'_1$, which is equal to $Q'_2$, is fixed for each transformation ratio.

| n | 2 | 4 | 8 | 10 | 16 |
|---|---|---|---|---|---|
| $Q'_1 = Q'_2$ | 0.65 | 1 | 1.35 | 1.46 | 1.73 |

$$Q' = \sqrt{\sqrt{n} - 1}$$

The maximum value of reactance that the terminations may have for use in this configuration can be determined from the above values of Q'.

If R1 is the load resistance of a transistor, the internal transistor resistance may not be equal to $R_1$. In this case the selectivity curve will be different from the curves given in Figure 14. Figure 15 shows the selectivity for networks (a) and (b) when the source resistance $R_1$ is infinite.

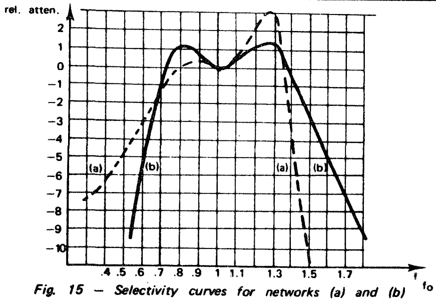



*Fig. 15 – Selectivity curves for networks (a) and (b) of Fig. 13 with infinite $R_1$*

From Figure 15 it can be seen that network (a) is more sensitve to $R_1$ changes than network (b).

As mentioned earlier, the four-reactance network can also be thought of as two cascaded two-reactance sections; one used for transformation, the other for compensation. Figure 16 shows commonly used compensation networks, together with the associated L-section.

The circuit of Figure 16 (a) can be compared to the three-reactance network shown in Figure 9 (c). The difference is that capacitor $C_2$ of that circuit has been replaced by a L-C circuit. The resulting improvement may be seen by comparing Figure 17 with Figure 11.

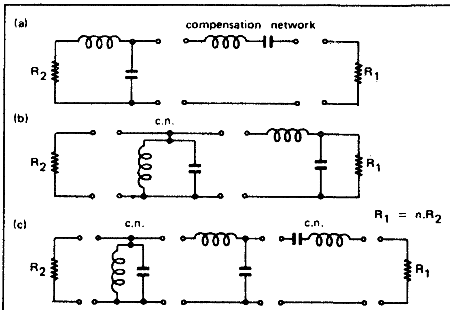
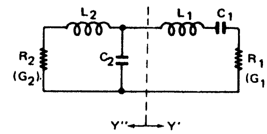



*Fig. 16 – Compensation networks used with a L-section*




$$Y' = G' + jB' = \frac{R_1}{R_1^2 + (\omega L_1 - 1/\omega C_1)^2} - \frac{j(\omega L_1 - 1/\omega C_1)}{R_1^2 + (\omega L_1 - 1/\omega C_1)^2}$$

$$Y'' = G'' + jB'' = \frac{R_2}{R_2^2 + \omega^2 L_2^2} + j\omega(C_2 - \frac{L_2}{R_2^2 + \omega^2 L_2^2})$$

$$B' = \pm\sqrt{\frac{G'}{R_1} - G'^2}$$

$$B'' = (1/kR_2 - G'')\sqrt{\frac{1}{G''R_2} - 1} \qquad k = \frac{L_2}{C_2 R_2^2}$$

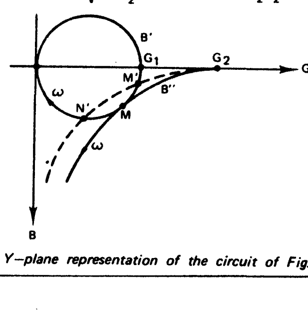



*Fig. 17 – Y–plane representation of the circuit of Fig. 16 (a)*

By adding one reactance, exact impedance transformation is achieved at two frequencies. It is now possible to choose component values such that the point of intersection M' occurs at the same frequency $f_1$ on both curves and simultaneously that N' occurs at the same frequency $f_2$ on both curves. Among the infinite number of possible intersections, only one allows to achieve this.

When M' and N' coincide in M, the new condition $\frac{dX'}{df} = \frac{dX''}{df}$ can be added to the condition $X' = -X''$ (for three-networks) and similarly $R' = R''$ and $\frac{dR'}{df} = \frac{dR''}{df}$.

If $f_1$ is made different from $f_2$, a larger bandwidth can be achieved at the expense of some ripple inside the band.

Again, a general solution of the above equations leads to still more complicated calculations than in the case of three-reactance networks. Therefore, tables are preferable (Ref. (3), (4) and (6)).

The circuit of Figure 16 (b) is dual of the circuit of of Figure 14 (a) and does not need to be treated separately. It gives exactly the same results in the Z-plane. Figure 16 (c) shows a higher order compensation requiring six reactive elements.

The above discussed matching networks employing compensation circuits result in narrower bandwidths than the former solutions (see paragraph 4.1.3) using two transformation sections. A matching with higher order compensation such as in Figure 16 (c) is not recommended. Better use can be made of the large number of reactive elements using them all for transformation.

When the above configurations are realized using short portions of transmission lines, the equations or the usual tables no longer apply. The calculations must be carried out on a computer, due to the complexity. However, a graphic method can be used (see next section) which will consist essentially in tracing a transformation path on the Z-Y-chart using the computed lumped element values and replacing it by the closest path obtained with distributed constants. The bandwidth change is not significant as long as short portions of lines are used (Ref. (13)).

### 4.1.4 Matching networks using quarter-wave transformers

At sufficiently high frequencies, where $\lambda/4$-long lines of practical size can be realized, broadband transformation can easily be accomplished by the use of one or more $\lambda/4$-sections.

Figure 18 summarizes the main relations for (a) one-section and (b) two-section transformation.

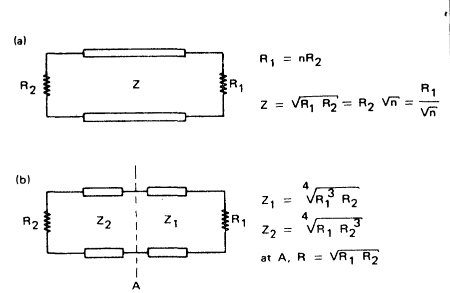



*Fig. 18 – Transformation networks using $\lambda/4$-long transmission lines*

A compensation network can be realized using a $\lambda/2$-long transmission line.

Figures 19 and 20 show the selectivity curves for different transformation ratios and section numbers.

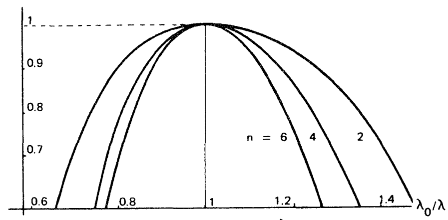



*Fig. 19 – Selectivity curves for two $\lambda/4$-section networks at different transformation ratios*

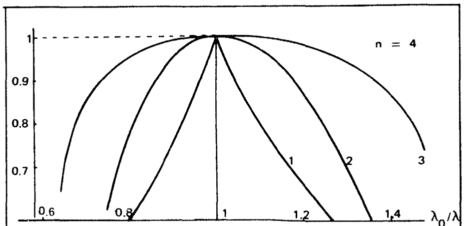



*Fig. 20 – Selectivity curves for one, two and three $\lambda/4$-sections*

Exponential lines

Exponential lines have largely frequency independent transformation properties.

The characteristic impedance of such lines varies exponentially with their length l:

$$Z = Z_0 \cdot e^{kl}$$

where k is a constant,
but these properties are preserved only if k is small.

#### 4.1.5 Broadband matching using band-pass filter type networks. High Q case.

The above circuits are applicable to devices having low input or output Q, if broadband matching is required. Generally, if the impedances to be matched can be represented for instance by a resistor R in series with an inductor L (sometimes a capacitor C) within the band of interest and if L is sufficiently low, the latter can be incorporated into the first inductor of the matching network. This is also valid if the representation consists of a shunt combination of a resistor and a reactance

Practically this is feasible for Q's around one or two. For higher Q's or for input impedances consisting of a series or parallel resonant circuit (see Fig. 2), as it appears to be for large bandwidths, a different treatment must be followed.

Let us first recall that, as shown by Bode and Fano (Ref. (7) and (8)), limitations exist on the impedance matching of a complex load. In the example of Figure 21, the load to be matched consists of a capacitor C and a resistor R in shunt.

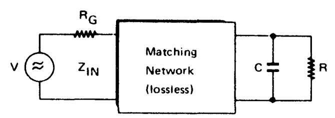



*Fig. 21 – General matching conditions*

The reflection coefficient between transformed load and generator is equal to:

$$\Gamma = \frac{Z_{IN} - R_g}{Z_{IN} + R_g}$$

$\Gamma = 0$, perfect matching,

$\Gamma = 1$, total reflection.

The ratio of reflected to incident power is:

$$\frac{Pr}{Pi} = |\Gamma|^2$$

The fundamental limitation on the matching takes the form:

$$\int_{\omega=0}^{\infty} \ln\left(\frac{1}{|\Gamma|}\right) d\omega \leqslant \frac{\pi}{RC} \qquad \text{Bode equation}$$

and is represented in Figure 22.

The meaning of Bode equation is that the area S under the curve cannot be greater than $\frac{\pi}{RC}$ and therefore, if matching is required over a certain bandwidth, this can only be done at the expense of less power transfer within the band. Thus, power

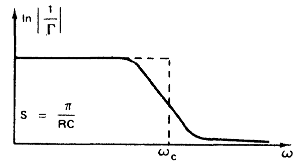



*Fig. 22 – Representation of Bode equation*

transfer and bandwidth appear as interchangeable quantities.

It is evident that the best utilization of the area S is obtained when $|\Gamma|$ is kept constant over the desired band $\omega_c$ and made equal to 1 over the rest of the spectrum. Then $|\Gamma| = e^{-\frac{\pi}{\omega_c RC}}$ within the band and no power transfer happens outside.

A network fulfilling this requirement cannot be obtained in practice as an infinite number of reactive elements would be necessary.

If the attenuation a is plotted versus the frequency for practical cases, one may expect to have curves like the ones shown in Figure 23 for a low-pass filter having Tchebyscheff character.

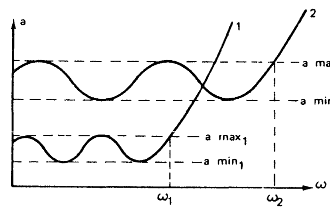



*Fig. 23 – Attenuation versus angular frequency for different bandwidths with same load*

For a given complex load, an extension of the bandwidth from $\omega_1$ to $\omega_2$ is possible only with a simultaneous increase of the attenuation a. This is especially noticeable for Q's exceeding one or two (see Figure 24).

Thus, devices having relatively high input Q's are useable for broadband operation, provided the consequent higher attenuation or reflection introduced is acceptable.

The general shape of the average insertion losses or attenuation a (neglecting the ripple) of a low-pass impedance matching network is represented in Figure 24 as a function of 1/Q for different numbers of network elements n (ref. (3)).

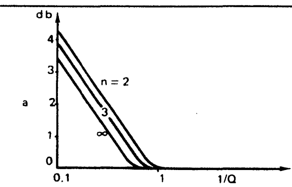



*Fig. 24 – Insertion losses as a function of 1/Q*

For a given Q and given ripple, the attenuation decreases if the number n of the network elements increases. But above n = 4, the improvement is small.

For a given attenuation a and bandwidth, the larger n the smaller the ripple.

For a given attenuation and ripple, the larger n the larger the bandwidth.

Computations show that for $Q < 1$ and $n \leqslant 3$ the attenuation is below 0.1 db approximately. The impedance transformation ratio is not free here. The network is a true low-pass filter. For a given load, the optimum generator impedance will result from the computation.

Before impedance transformation is introduced, a conversion of the low-pass prototype into a band-pass filter type network must be made. Figure 25 summarizes the main relations for this conversion.

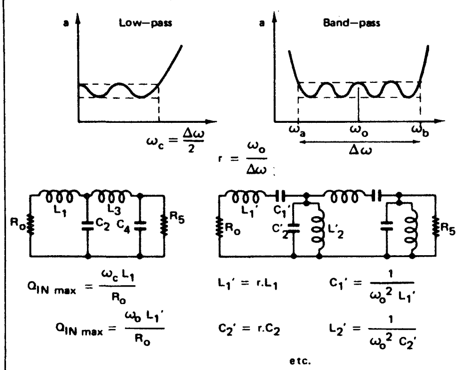



*Fig. 25 – Conversion from low–pass into band–pass filter*

r is the conversion factor.

For the band-pass filter, $Q_{IN}$ max or the maximum possible input Q of a device to be matched, has been increased by the factor r (from Figure 25, $Q'_{IN\ max} = r.Q_{IN\ max}$).

Impedance inverters will be used for impedance transformation. These networks are suitable for insertion into a band-pass filter without affecting the transmission characteristics.

Figure 26 shows four impedance inverters. It will be noticed that one of the reactances is negative and must be combined in the band-pass network with a reactance of at least equal positive value. Insertion of the inverter can be made at any convenient place (Ref. (3) and (9)).

When using the band-pass filter for matching the input impedance of a transistor, reactances $L'_1$ $C'_1$ should be made to resonate at $\omega_o$ by addition of a convenient series reactance.

As stated above, the series combination of Ro, $L'_1$ and $C'_1$ normally constitutes the equivalent input network of a transistor when considered over a large bandwidth. This is a good approximation up to about 500 MHz.

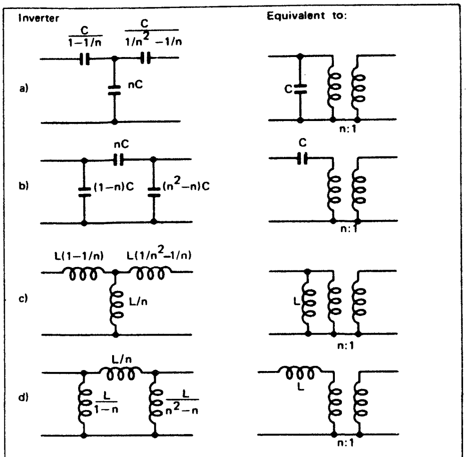



*Fig. 26 – Impedance inverters*

In practice the normal procedure for using a band-pass filter type matching network will be the following:

(1) For a given bandwidth, center frequency and input impedance of a device to be matched e.g. to 50 ohms, first determine $Q_{IN}'$ from the data sheet as $\frac{\omega_o L'_1}{R_o}$ after having eventually added a series reactor for centering,

(2) Convert the equivalent circuit $R_oL_1'$ $C_1'$ into a low-pass prototype $R_o$ $L_1$ and calculate $Q_{IN}$ using the formulas of Figure 25,

(3) Determine the other reactance values from tables (Ref. (3)) for the desired bandwidth,

(4) Convert the element values found by step (3) into series or parallel resonant circuit parameters,

(5) Insert the impedance inverter in any convenient place.

In the above discussions, the gain roll-off has not been taken into account. This is of normal use for moderate bandwidths (30% for ex.). However, several methods can be employed to obtain a constant gain within the band despite the intrinsic gain decrease of a transistor with frequency.

Tables have been computed elsewhere (Ref. (10)) for matching networks approximating 6 db/octave attenuation versus frequency.

Another method consists in using the above mentioned network and then to add a compensation circuit as shown for example in Figure 27.

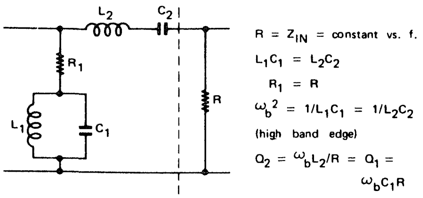



*Fig. 27 – Roll–off compensation network*

Resonance $\omega_b$ is placed at the high edge of the frequency band. Choosing Q correctly, roll-off can be made 6 db/octave.

The response of the circuit shown in Figure 27 is expressed by:

$$\frac{1}{1+Q^2\left(\frac{\omega}{\omega_b}-\frac{\omega_b}{\omega}\right)^2}\text{, where } \omega<\omega_b$$

This must be equal to $\frac{\omega}{\omega_b}$ for 6db/octave compensation.

At the other band edge a, exact compensation can be obtained if:

$$Q=\frac{\left(\frac{\omega_b}{\omega_a}\right)^2-1}{\frac{\omega_a}{\omega_b}-\left(\frac{\omega_b}{\omega_a}\right)^2}$$

### 4.1.6 Line Transformers

The broadband properties of line transformers make them very useful in the design of broadband impedance matching networks (Ref. (11) and (12)).

A very common form is shown by Figure 28. This is a 4:1 impedance transformer. Other transformation ratios like 9 : 1 or 16 : 1 are also often used but will not be considered here.

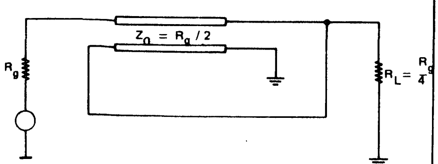



*Fig. 28 – 4:1 line transformer*

The high frequency cut-off is determined by the length of line which is usually chosen smaller than λ min/8. Short lines extend the high frequency performance.

The low frequency cut-off is determined first by the length of line, long lines extending the low frequency performance of the transformer. Low frequency cut-off is also improved by a high even mode impedance, which can be achieved by the use of ferrite material. With matched ends, no power is coupled through the ferrite which cannot saturate.

For matched impedances, the high frequency attenuation a of the 4 : 1 transformer is given by:

$$a=\frac{(1+3\cos 2\pi\, l/\lambda)^2+4\sin^2 2\pi\, l/\lambda}{4(1+\cos 2\pi\, l/\lambda)^2}$$

For $l = \lambda/4$, a = 1.25 or 1 db ; for $l = \lambda/2$, $a = \infty$ .

The characteristic impedance of the line transformer must be equal to:

$$Zo = \sqrt{Rg.R}\ .$$

Figures 29 and 30 show two different realizations of 4 : 1 transformers for a 50 to 12.5 ohm-transformation designed for the band 118-136 MHz.

The transformers are made of two printed circuit boards or two ribbons stuck together and connected as shown in Figures 29 and 30.

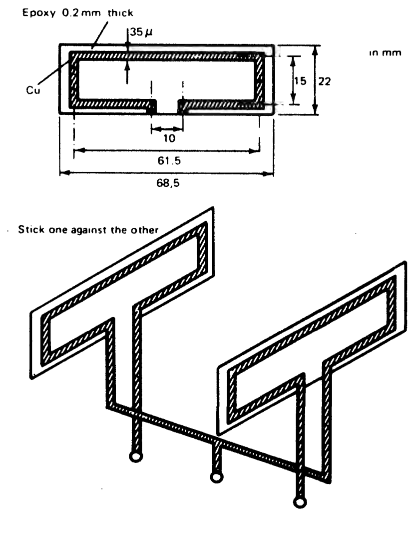
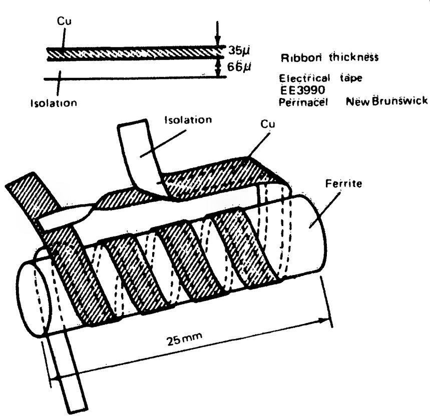



*Fig. 29 – 4:1 line transformer on p.c. board*

*Line transformer on p.c. board (Fig. 29)*




- Stick one ribbon (1.5mm wide) against the other (2 5)
Total length per ribbon ≃ 9cm.
Turns 3 5

*Fig. 30 – 4:1 copper ribbon line transformer with ferrite*

*Line transformer on ferrite (Fig. 30)*

## 4.2 GRAPHIC DESIGN

The common method of graphic design makes use of the Impedance-Admittance Chart (Smith Chart).

It is applicable to all ladder-type networks as encountered in matching circuits.

Matching is supposed to be realized by the successive algebraic addition of reactances (or susceptances) to a given start impedance (or admittance) until another end impedance (or admittance) is reached.

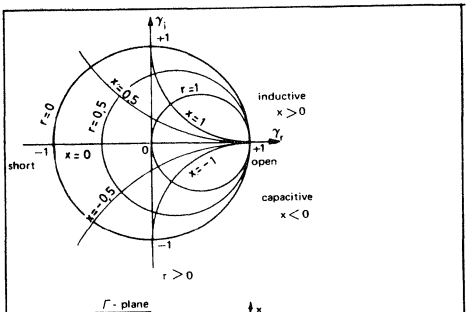
Impedance chart and admittance chart can be superimposed and used alternatively due to the fact that an immittance point, defined by its reflection coefficient $\Gamma$ with respect to a reference, is common to the Z-chart and the Y-chart, both being representations in the $\Gamma$-plane.

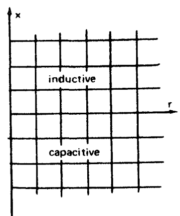
$$\Gamma = \frac{Z-R_S}{Z+R_S} = \gamma_r + j\gamma_i$$

$$\Gamma = \frac{G_S-Y}{G_S+Y} \qquad R_S = \frac{1}{G_S} = \text{Characteristic impedance of the line}$$

More precisely, the Z-chart is a plot in the $\Gamma$-plane, while the Y-chart is a plot in the $-\Gamma$-plane. The change from the $\Gamma$ to $-\Gamma$-plane is accounted for in the construction rules given below.

Figure 31 and 32 show the representation of normalized Z and Y respectively, in the $\Gamma$-plane.




$$\frac{Z}{R_s} = z = r + jx$$

$$r = \frac{1-\gamma_r^2-\gamma_i^2}{(1-\gamma_r)^2+\gamma_i^2}$$

$$x = \frac{2\gamma_i}{(1-\gamma_r)^2+\gamma_i^2}$$

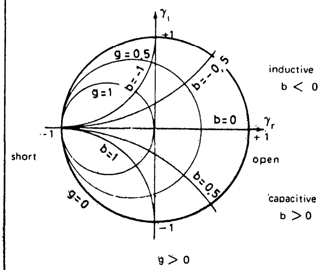
$$\gamma_r = \frac{r^2+x^2-1}{(r+1)^2+x^2}$$

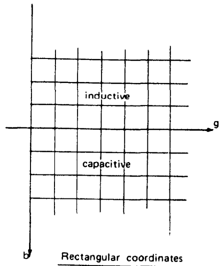
$$\gamma_i = \frac{2x}{(r+1)^2+x^2}$$

r circles: Radius: $1/(1+r)$; Center at: $\gamma_r = \frac{r}{1+r}$, $\gamma_i = 0$

x circles: Radius: $1/x$; Center at: $\gamma_r = 1$, $\gamma_i = 1/x$

***Fig. 31 – Representation of the normalized Z values in the Γ-plane***




$$\frac{Y}{G_s} = y = g + jb$$

$$g = \frac{1-\gamma_r^2-\gamma_i^2}{(1+\gamma_r)^2+\gamma_i^2}$$

$$b = \frac{-2\gamma_i}{(1+\gamma_r)^2+\gamma_i^2}$$

$$\gamma_r = \frac{1-g^2-b^2}{(1+g)^2+b^2}$$

$$\gamma_i = \frac{-2b}{(1+g)^2+b^2}$$

g circles: Radius : $1/(1+g)$; Center at: $\gamma_r = -g/(1+g)$; $\gamma_i = 0$

b circles: Radius : $1/b$; Center at : $\gamma_r = -1$, $\gamma_i = -1/b$

*Fig. 32 – Representation of the normalized Y–values in the Γ– plane*

The Z-chart is used for the algebraic addition of series reactances. The Y-chart is used for the algebraic addition of shunt reactances.

For the practical use of the charts, it is convenient to make the design on transparent paper and then place it on a usual Smith-chart of impedance type (for example). For the addition of a series reactor, the chart will be placed with "short" to the left. For the addition of a shunt reactor, it will be rotated by 180° with "short" (always in terms of impedance) to the right.

The following design rules apply. They can very easily be found by thinking of the more familiar Z and Y representation in reactangular coordinates.

For joining two impedance points, there are a infinity of solutions. Therefore, one must first decide on the number of reactances that will constitute the matching network. This number is related essentially to the desired bandwidth and the transformation ratio.

| Addition of | Chart to be used | Direction | Using curve of constant |
|---|---|---|---|
| series R | Z | open (in terms of admittance) | x |
| series G | Y | short (in terms of admittance) | b |
| series C $(+\frac{1}{j\omega C})$ | Z | ccw | r |
| shunt C $(+j\omega C)$ | Y | cw | g |
| series L $(+j\omega L)$ | Z | cw | r |
| shunt L $(+\frac{1}{j\omega L})$ | Y | ccw | g |

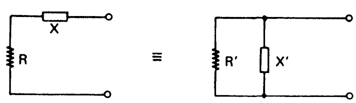
Secondly, one must choose the operating Q of the circuit, which is also related to the bandwidth. Q can be defined at each circuit node as the ratio of the reactive part to the real part of the impedance at that node. The Q of the circuit, which is normally referred to, is the highest value found along the path.

Constant Q curves can be superimposed to the charts and used in conjunction with them. In the Γ -plane, Q-curves are circles with a radius equal to $\sqrt{1+\frac{1}{Q^2}}$ and a center at the point $\pm\frac{1}{Q}$ on the imaginary axis, which is expressed by:

$$Q = \frac{x}{r} = \frac{2\gamma_i}{1-\gamma_r^2-\gamma_i^2} \qquad \gamma_r^2 + (\gamma_i + \frac{1}{Q})^2 = 1 + \frac{1}{Q^2}$$

The use of the charts will be illustrated with the help of an example.

The following series shunt conversion rules also apply:




$$R = \frac{R'}{1+\frac{R'^2}{X'^2}} \qquad G' = \frac{1}{R'} = \frac{R}{R^2+X^2}$$

$$X = \frac{X'}{1+\frac{X'^2}{R'^2}} \qquad -B' = \frac{1}{X'} = \frac{X}{R^2+X^2}$$

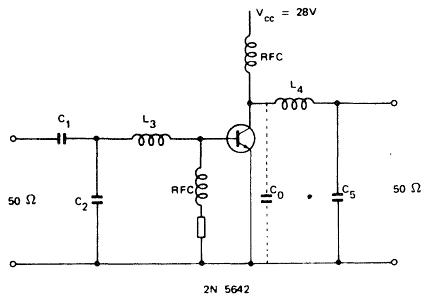



*Fig. 33 – Narrow-band VHF power amplifier*

Figure 33 shows the schematic of an amplifier using the 2N5642 RF power transistor. Matching has to be achieved at 175 MHz, on a narrow band basis.

The rated output power for the device in question is 20 W at 175 MHz and 28 V collector supply. The input impedance at these conditions is equal to 2.6 ohms in parallel with -200 pF (see data Sheet). This converts to a resistance of 1.94 ohms in series with a reactance of 1.1 ohm.

The collector load must be equal to:

$$\frac{[\,Vcc - Vce\ (sat)\,]^2}{2 \times P_{out}} \quad \text{or} \quad \frac{(\,28-3\,)^2}{40} \quad = \quad 15.6 \text{ ohms.}$$

The collector capacitance given by the data sheet is 40 pF, corresponding to a capacitive reactance of 22.7 ohms.

The output impedance seen by the collector to insure the required output power and cancel out the collector capacitance must be equal to a resistance of 15.6 ohms in parallel with an inductance of 22.7 ohms. This is equivalent to a resistance of 10.6 ohms in series with an inductance of 7.3 ohms.

The input Q is equal to, 1.1/1.94 or 0.57 while the output Q is 7.3/10.6 or 0.69.

It is seen that around this frequency, the device has good broadband capabilities. Nevertheless, the matching circuit will be designed here for a narrow band application and the effective Q will be determined by the circuit itself not by the device.

Figure 34 shows the normalized impedances (to 50 ohms).

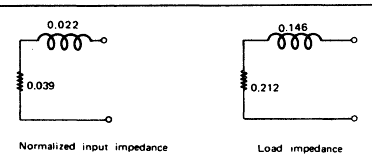



*Fig. 34 – Normalized input and output impedances for the 2N5642*

Figure 35 shows the diagram used for the graphic design of the input matching circuit. The circuit Q must be larger than about 5 in this case and has been chosen equal to 10. At Q = 5, $C_1$ would be infinite. The addition of a finite value of $C_1$ increases the circuit Q and therefore the selectivity. The normalized values between brackets in the Figure are admittances (g + jb).

At f = 175MHz, the following results are obtained:

$$\omega L_3 = 50 x_3 = 50\ (0.39 - 0.022) = 18.5 \text{ ohms} \qquad \therefore L_3 = 16.8 \text{ nH}$$

$$\omega C_2 = \frac{1}{50}\, b_2 = \frac{1}{50}\ (2.5 - 0.42) = 0.0416 \text{ mhos} \qquad \therefore C_2 = 37.8 \text{ pF}$$

$$\frac{1}{\omega C_1} = 50 x_1 = 50 \,.\, 1.75 = 87.5 \text{ ohms} \qquad \therefore C_1 = 10.4 \text{ pF}$$

Figure 36 shows the diagram for the output circuit, designed in a similar way.

Here, the results are ( f = 175MHz ) :

$$\omega L_4 = 50.x_4 = 50\ .\ (0.4 + 0.146) = 27.3 \text{ ohms} \qquad \therefore L_4 = 24.8 \text{ nH}$$

$$\omega C_5 = \frac{1}{50}\, b_5 = \frac{1}{50}\ .\ 1.9 = 0.038 \text{ mhos} \qquad \therefore C_5 = 34.5 \text{ pF}$$

The circuit Q at the output is equal to 1.9.

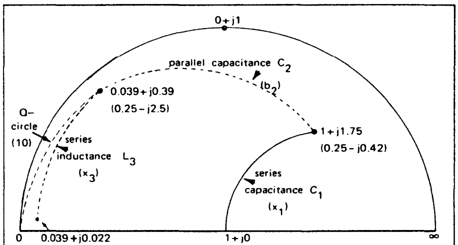



*Fig. 35 – Input circuit design*

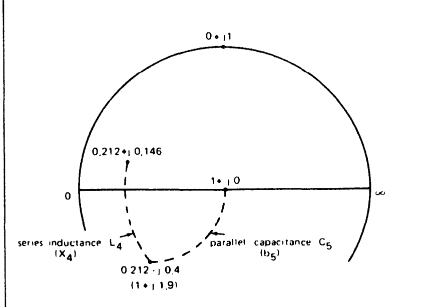



*Fig. 36 – Output circuit design*

The selectivity of a matching circuit can also be determined graphically by changing the x or b values according to a chosen frequency change. The diagram will give the VSWR and the attenuation can be computed.

The graphic method is also useful for conversion from a lumped circuit design into a stripline design. The immittance circles will now have their centres on the 1 + jo point.

At low impedance levels (large circles), the difference between lumped and distributed elements is small.

# 5. PRACTICAL EXAMPLE

The example shown refers to a broadband amplifier stage using a 2N 6083 for operation in the VHF-band 118-136 MHz. The 2N 6083 is a 12.5 V-device and, since amplitude modulation is used at these transmission frequencies, that choice supposes low level modulation associated with a feedback system for distortion compensation.

Line transformers will be used at the input and output. Therefore the matching circuits will reduce to two-reactance networks, due to the relatively low impedance transformation ratio required.

## 5.1 DEVICE CHARACTERISTICS

Input impedance of the 2N 6083 at 125 MHz:

$$R_p = 0.9 \text{ ohms}$$

$$C_p = -390 \text{ pF}$$

Rated output power:

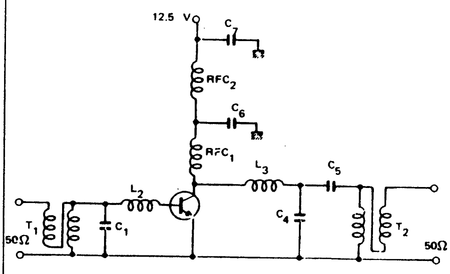
30W for 8W input at 175MHz. From the data sheet it appears that at 125MHz, 30W output will be achieved with about 4W input.

Output impedance:

$$\frac{[V_{cc} - V_{ce\,(sat)}]^2}{2 \times P_{out}} = \frac{100}{60} = 1.67 \text{ ohms}$$

$$C_{out} = 180 \text{ pF at } 125 \text{ MHz}$$

## 5.2 CIRCUIT SCHEMATIC




$C_1$ = 300 pF (chip)
$L_2$ = 4.2 nH (adjust)
$L_3$ = 8 nH (adjust)
$C_4$ = 130 pF (chip)
$C_5$ = 750 pF (chip)
$C_6$ = 2.2 μF

$T_1$, $T_2$ see Figure 30
$RFC_1$ = 7 turns
6.3 mm coil diameter
0.8 mm wire diameter
$RFC_2$ = 3 turns on ferrite bead
$C_7$ = 0.68 μF

*Fig. 37 – Circuit schematic*

## 5.3 TEST RESULTS

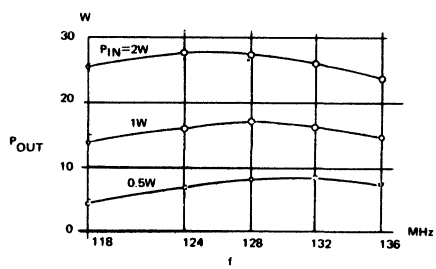



*Fig. 38 – $P_{OUT}$ vs frequency*

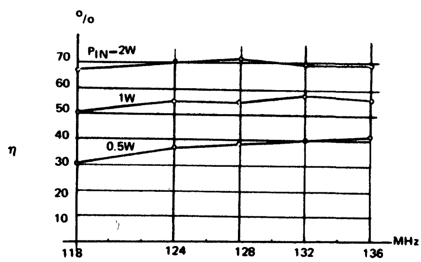



*Fig. 39 – η vs. frequency*

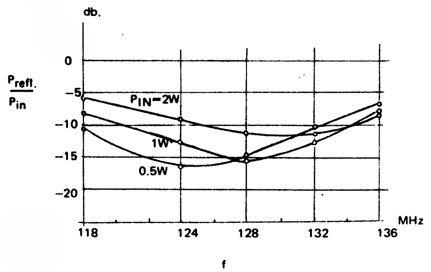
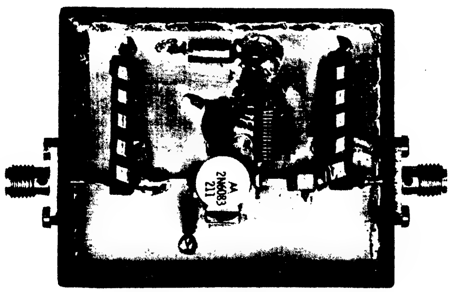



*Fig. 40 – $P_{REFL.}/P_{IN}$ vs frequency*



*118-136 MH2 amplifier (see Fig. 37) before coil adjustment.*

Acknowledgements:
The author is indebted to Mr. T. O'Neal for the fruitful discussions held with him. Mr. O'Neal designed the circuit shown in Figure 37; Mr. J. Hennet constructed and tested the lab model.

# 6. LITERATURE

1. Motorola Application Note AN-282 A "Systemizing RF Power Amplifier Design"

2. W. E. Everitt and G. E. Anner
"Communication Engineering"
McGraw-Hill Book Company, Inc.

3. G. L. Matthaei, L. Young, E. M. T. Jones
"Microwave Filters, Impedance-Matching Networks and Coupling Structures"
McGraw-Hill Book Company, Inc.

4. G. L. Matthaei
"Tables of Chebyshew Impedance-Transforming Networks of Low-Pass Filter Form"
Proc. IEEE, August 1964

5. Motorola Application Note AN-267
"Matching Network Designs with Computer Solutions"

6. E. G. Cristal
"Tables of Maximally Flat Impedance-Transforming Networks of Low-Pass-Filter Form"
IEEE Transactions on Microwave Theory and Techniques
Vol. MTT 13, No 5, September 1965
Correspondence

7. H. W. Bode
"Network Analysis and Feedback Amplifier Design"
D. Van Nostrand Co., N.Y.

8. R. M. Fano
"Theoretical limitations on the Broadband Matching of Arbitrary Impedances"
Journal of Franklin Institute, January-February 1950

9. J. H. Horwitz
"Design Wideband UHF-Power Amplifiers"
Electronic Design 11, May 24, 1969

10. O. Pitzalis, R. A. Gilson
"Tables of Impedance Matching Networks which Approximate Prescribed Attenuation Versus Frequency Slopes"
IEEE Transactions on Microwave Theory and Techniques
Vol. MTT-19, No 4, April 1971

11. C. L. Ruthroff
"Some Broadband Transformers"
Proc. IRE, August 1959

12. H. H. Meinke
"Theorie der H. F. Schaltungen"
München, Oldenburg 1951

# RF TRANSISTOR DESIGN — CHAPTER 18

## Class C Power

The primary concern of the RF transistor designer is meeting the requirements for output power, gain, and ruggedness at the specified frequency and supply voltage.

Most RF applications typically require 12.5 or 28 volt operation of a power device in a mobile transmitter, base station, or avionics application. This choice dictates the epitaxial layer resistivity. Low resistivity, about 1 ohm/cm, is used for mobile devices, while 28 V base station and avionics devices are usually built using epi with 2 ohm/cm resistivity. Epi resistivity controls collector breakdown voltage, since the resistivity value determines the maximum possible breakdown voltage. Typically, a particular device rarely achieves this bulk breakdown value because of junction curvature and surface effects. When high voltages are present in an amplifier, high breakdown voltages are needed if the transistor is to survive. High voltage breakdowns are usually obtained by such added features as collector depletion rings, or by a high voltage diffusion surrounding the relatively shallow RF base diffusion. Voltages in excess of 150 volts are easily obtained this way.

Output power is determined primarily by the "electrical size" of the chip. Two common methods of sizing are emitter diffusion periphery and base diffusion area. Emitter periphery sizing is based on the premise that there is some optimum current which should be injected for each mil of emitter periphery. The base area sizing is based on an optimum power density. Both of these techniques are oversimplifications which make it impossible to apply them to widely varying device geometries and applications. Motorola uses a different method of sizing based on each geometry's Current Factor. Current Factor values are obtained by considering both emitter periphery effects and power density. Proper weighting of both factors makes this technique of sizing widely applicable. No matter what sizing technique is chosen, the end result is that greater power-handling capability requires larger chips. Small-signal devices, with only a few milliwatts of output power, and large devices with 100 watts output, range from current factors of only 1 to nearly 2000.

An alternative approach to high output power is to use several smaller chips in parallel. Unless extreme care is taken, this approach can result in unequal current and power sharing. Single large chips are also susceptible to this sharing problem unless specific steps are taken to ensure even current distribution. The primary method of handling this problem is by the use of well-designed emitter resistor layouts. The lowest value of emitter resistance on a chip is chosen to prevent thermal runaway up to the highest temperatures the device may encounter, possibly up to 300°C during output impedance mismatch conditions. An appropriate matrix of emitter resistance values is constructed so that the overall current distribution among the many parallel emitter sites results in an even thermal distribution. Verification of thermal balance is obtained by precise infrared microscope measurements across the entire chip.

The thermal balance of larger chips is also improved considerably by "cell spreading." In this techique the base diffusion area is broken up into smaller areas, or cells, and each cell is sufficiently removed from those adjacent to eliminate thermal interaction. The net effect is to achieve lower thermal resistance. This is exceedingly important in large devices where high power dissipation levels can cause excessive junction temperature when thermal resistance is not minimized. Some symptoms of excessively high temperature operation are low efficiency, power slump, and, frequently, total device failure.

The overall ruggedness of a transistor is enhanced by many techniques. All of them are aimed at preventing two things: junction breakdown due to excessive voltages and failure due to hot-spotting. Here again, epitaxial layer resistivity and thickness are used to alter breakdown voltages and saturated output power. Thermal balancing by base cell spreading and using emitter resistors also has a strong effect on ruggedness. These techniques are commonly referred to as collector and emitter ballasting. Ballasting of either type can improve ruggedness for a fixed geometry size (current factor), but there is a definite trade-off with gain. Usually increasing ruggedness requires decreasing gain unless one is willing to pay the penalty of the cost of larger die.

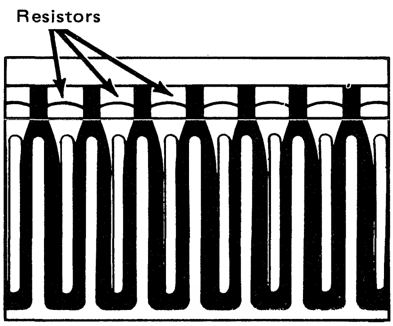
Large die can also adversely affect gain, since it is a practical fact that gain decreases by 2 dB for each doubling in current factor. To offset this gain decrease, the designer has another technique available—increase the packing denisty within the chip. The most common method of measuring packing density is with the figure of merit obtained from the ratio of emitter periphery (Ep) to base area ($B_A$) of the chip. Higher $Ep/B_A$ ratios result in higher gain. Typically, $Ep/B_A$ ratios are as shown in the table.

| $E_P/B_A$ | FREQUENCY | GEOMETRY TYPE |
|---|---|---|
| 0.5–1.5 | 3-30 MHz | Interdigitated |
| 1.5–3.5 | VHF | Interdigitated or Spine (Overlay) |
| 3.5–4.5 | UHF | Spine (Overlay) or Mesh (Network) |
| 5.5–6.5 | 800-900 MHz | Mesh |

Higher $E_P/B_A$ ratios generally mean greater processing difficulties. These difficulties are somewhat offset by the choice of geometry type. Fundamentally, the interdigitated geometry requires narrow spacing between emitter and base fingers and narrow finger widths. The maximum $E_P/B_A$ ratio obtainable with an interdigitated structure of uniform spacing "S" is given by

$$(E_P/B_A)\ MAX = \frac{0.45}{S}.$$

Spacings of 0.08 mil are the minimum easily obtainable with current technology, giving a maximum figure of merit of 5.6. Actual devices with this spacing are usually about 4.5. Building a large power device using this geometry calls for a great many narrow metallization fingers.




Enlargement of this "interdigitated" geometry shows emitter resistors that have been added to balance the current throughout the chip.

This approach increases the probability of a metallization defect linking adjoining fingers and enhances failures due to metal migration. The spine or mesh geometries used for higher figure of merit do not completely relieve the tight spacing requirements. In both cases, tight metal spacing is relieved while diffusion spacings are not. For example, 4.5 is the maximum $E_P/B_A$ ratio for a 0.1 mil spacing with an interdigitated device. Motorola's family of UHF power devices MRF641 (15 watt), MRF644 (25 watt), MRF646 (45 watt), and MRF648 (60 watt) are constructed using a split mesh (adjoining emitter fingers are not interconnected). All four devices have an $E_P/B_A$ ratio of 4 and are built with a 0.1 mil spacing between adjacent emitter and P+ diffusion areas. Similar tight spacing is required in the mesh geometry used for the 800-900 MHz 7, 20, 30, and 40 watt devices. Here the spacing is reduced to 0.06 mil, using a mesh geometry. Without tight spacing of emitter to P+ such as these devices have, high $E_P/B_A$ ratios will not produce good gain. The introduction of the P+ is required to maintain full utilization of all elements of the emitter periphery. Introducing undulations in the shape of the emitter to increase the periphery without a closely spaced P+ will cause some elements of the periphery to be debiased due to uneven base voltage drops.

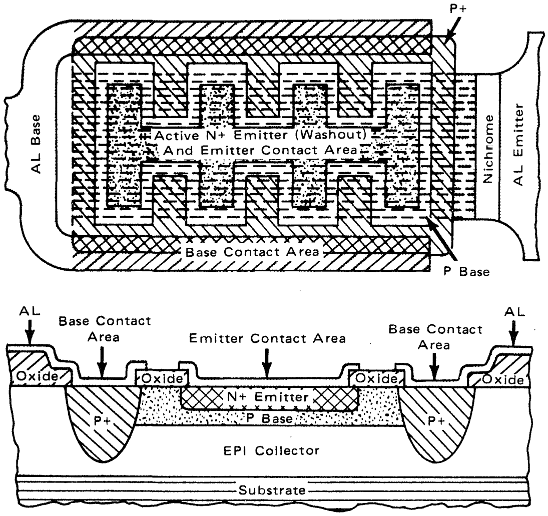
The metal migration failure rate as measured by MTBF (Mean Time Before Failure) depends on current density, metallization cross-sectional area, and activation energy. Activation energy may be varied by the choice of metallization with gold and aluminum being the two most common choices. Motorola uses gold metallization for both avionics and 28 volt base station devices where continuous operation is anticipated. Mobile devices are usually constructed of aluminum. In either case, devices are designed for a minimum of 10 years MTBF.

## Linear Power

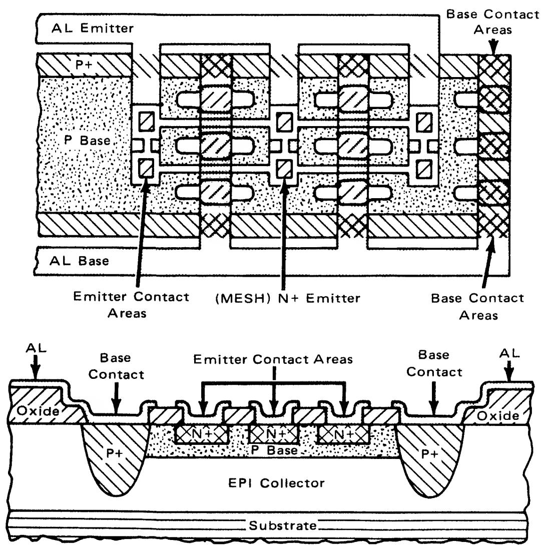
Linear operation is usually accomplished by building the same type of transistor structure as used in Class C operation. The major difference is the linearity requirements force the use of devices with larger current factors. They are also usually fabricated with slightly lower collector resistivity. The combination of these factors allows the device to maintain good linearity with high power output levels. Motorola has led the industry with its family of SSB large-chip transistors, MRF421, MRF422, MRF428. These chips are large, 140 X 250 mils, and have Current Factors approaching 2000. The higher voltage devices are built using a combination of both depletion rings and deep P+ high voltage diffusions. All feature thermal ballasting through emitter resistor matrices.

## Small Signal

Small-signal devices are constructed from the same types of geometries as used for power devices except on a much smaller scale of Current Factor. The small geometries do not suffer from the gain reduction due to size, allowing the use of lower $E_P/B_A$ ratios for equivalent gain.




**Overlay Structure.** Individual emitter cell blocks are diffused into a common base region. Emitter interconnection runs are made over a passivating silicon dioxide layer, reducing the need for critically thin interdigitated metal fingers.




**Network Emitter Structure.** This structure maximizes emitter periphery to base area ratio but pays for it with increased production difficulty and increased contact resistance.

Motorola employs a thin nichrome barrier (not shown) between the silicon and the aluminum metalization in most network emitter and overlay devices to prevent aluminum metal migration thus improving long-term reliability.

Quite commonly, small-signal transistors are not only required to have a minimum gain, but also a minimum $f_t$. This parameter is a measure of the total emitter-to-collector transit time. As the collector current is increased, the value of $f_t$ increases initially, peaks, and then finally decreases. The peak value is determined by the base and emitter region transit times. This parameter is controlled by both the base junction depth and the emitter doping species. Using conventional diffusion processes with a single base and emitter diffusion, maximum achievable $f_t$ for NPN transistors is about 3–4 GHz without severely degrading the normally desirable dc characteristics, namely $BV_{CEO}$ and $h_{FE}$.

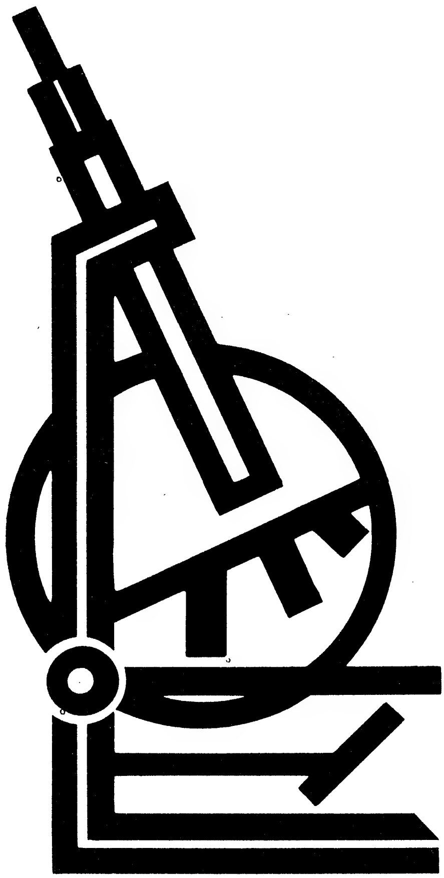
The logical solution is to use arsenic as the emitter dopant species. Arsenic has an advantage over the more commonly used phosphorus diffusion source. The concentration dependent diffusivity of arsenic causes a very abrupt emitter profile. The increased profile gradient reduces the storage of free carriers in the emitter space charge layer, reducing the layer transit time, and increasing $f_t$. Unfortunately, arsenic diffusion technology is difficult at best.

The simplest method for using arsenic as a dopant species is to implant it. Motorola has introduced a whole family of implanted arsenic emitter NPN transistors. These devices have typical $f_t$ of 6 GHz without sacrificing dc characteristics.

A family of low noise devices has also been fabricated using similar processes. Low noise figure (NF) places additional requirements on both $f_t$, the doping density of the base under the emitter, and the emitter diffusion width. Through special controlled processing, excellent NF values are obtained in the 1 to 2 GHz region. This performance requires high $f_t$, low base spreading resistance, and 0.05 mil wide arsenic implanted emitters.

# RELIABILITY AND QUALITY ASSURANCE

# CHAPTER 19



# RELIABILITY AND QUALITY ASSURANCE

## QUALITY LEVELS

RF Products are available from Motorola in three quality levels:

1. Industrial/commercial grade, identified by a prefix such as 2N, MRF, or MHW on the part number and tested to a published Corporate, JEDEC, or Proelectron specification.
2. Military grade, built and tested per MIL-S-19500 and identified by a 2N prefix and JAN, JTX, or JTXV suffix.
3. Customer-specified grade with screening, testing, and marking determined by the customer to meet his particular requirements. These may range from a custom-marked industrial/commercial grade product to a product which is subjected to the most stringent tests required for space or submarine applications.

## POST-ASSEMBLY PROCESSING

After assembly, a production lot is first sent to Final Test, then is transferred to Quality Assurance.

### Final Test Processing

In Final Test, 100% of a lot is processed. This processing may be as simple as electrical testing to a data sheet specification or as complex as a series of mechanical and environmental screening tests preceded and followed by electrical tests. In Final Test all lots, whether commercial or high-rel, receive a minimum of an eight-hour storage bake at 150 or 200°C.

### Quality Assurance Processing

Once in QA, high-rel lots may undergo additional 100% screening prior to testing. Using the popular 2N3866* family as an example, Table 1 compares the varying degrees of preconditioning and screening that are done on the 2N3866, 2N3866JAN, 2N3866JANTX and the 2N3866JTXV transistors. For testing, QA uses test sample groups A, B, and C as defined in MIL-STD 19500. Individual tests are defined in MIL-STD-202, 750, and 883. All lots, including industrial/commercial, receive Group A testing, usually to the same specification which is used by Final Test. In addition to the Group A tests, military and customer-specified high-rel specifications usually require Group B and C tests. Table 2 lists the standard LTPD, sample size and lot acceptance number used for Group A testing of standard products at Motorola. Military and high-rel specifications may call for a tighter Group A sample plan. Tables 3 and 4 list the Group B and C test requirements of the 2N3866JAN and 2N3866-JANTXV specifications.

### Special Processing

Three additional tests that may be specified at extra cost by a high-rel customer are:

1. Scanning electron microscope inspection of a wafer.
2. X-ray examination of metal can transistors.
3. Particle Inclusion Noise Detection (PIND) test to detect loose particles trapped in a package.

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*The 2N3866 is a 400 MHz, 1.0 Watt NPN silicon transistor mounted in a TO-39 metal can.

TABLE 1 — 100% PRECONDITIONING AND SCREENING (2N3866 Family)

| Test | MIL-S-750 Method | Condition | 2N3866/JAN | 2N3866JTX/V |
|---|---|---|---|---|
| Final Test | | | | |
| 1. Electrical Tests | | Go/No Go | | |
| (Same as Group A) | | Remove Rejects | 100% | 100% |
| 2. High Temperature Storage | | 200°C, 24 hours | Omit | 100% |
| 3. Temperature Cycling | 1051 | C, 10 cycles | Omit | 100% |
| 4. Constant Acceleration | 2006 | 20,000 G $Y_1$ | Omit | 100% |
| 5. Hermetic Seal | 1071 | | Omit | 100% |
| Fine Leak | | G or H | | |
| Gross Leak | | A, B, C, D or F | | |
| 6. HT R B | | 150°C, 48 hr, 24 V | Omit | 100% |
| 7. Electrical Tests | | | | |
| (Similar to Group A) | | | Omit | 100% |
| QA | | | | |
| 8. Electrical Tests | | Go/No Go | Omit | 100% |
| 9. Establish Identity | | | Omit | 100% |
| 10. Electrical Tests | $I_{CBO}$ and $h_{FE}$ | | Omit | 100% |
| 11. Burn In | with | 168 hr, 1.0 W | Omit | 100% |
| 12. Electrical Tests | Deltas | PDA = 10% | Omit | 100% |

TABLE 2 — STANDARD GROUP A SAMPLING PLANS* (Discrete Products)

| Characteristic (By Subgroup) | LTPD | Sample Size | Accept Number |
|---|---|---|---|
| Discrete Devices | | | |
| Visual and Mechanical | 3.0 | 129 | 1 |
| DC Parameters | 3.0 | 129 | 1 |
| AC and Temperature Parameters | 7.0 | 55 | 1 |
| Opens/Shorts | 1.75 | 129 | 0 |
| Discrete Wafers and Dice | | | |
| Visual and Mechanical | | | |
| Multipack and Decca Pack (100% Sorted) | 10 | 52 | 2 |
| Wafer Sales and Vial Package (no 100% Sort) | 20 | 69 | 9 |
| DC Parameters | 10 | 38 | 1 |
| AC and Temperature Parameters | 20 | 25 | 2 |

*Extracted from Motorola Specification 12MRBO2952A Issue D.

**TABLE 3 – GROUP B TESTS (2N3866 Family)**

| Inspection or Test | MIL-S-750 Method | Condition | LT P D (Accept No.) | |
|---|---|---|---|---|
| | | | 2N3866JAN | 2N3866JTX/V |
| Subgroup B-1 | | | 20(1) | 20(1) |
| Physical Dimensions | 2066 | | | |
| Subgroup B-2 | | | 15(1) | 15(1) |
| Solderability | 2026 | | | |
| Temperature Cycling | 1051 | C | | |
| Thermal Shock | 1056 | B | | |
| Hermeticity | 1071 | | | |
| Fine Leak | | IIIa G or H | | |
| Gross Leak | | A, B, C, D or F | | |
| Moisture Resistance | 1021 | | | |
| Subgroup B-3 | | | 15(1) | 15(1) |
| Shock | 2016 | 1500 G | | |
| Variable Freq. Vib | 2056 | | | |
| Constant Acceleration | 2006 | 20,000 G | | |
| Subgroup B-4 | | | 20(1) | 20(1) |
| Lead Fatigue | 2036 | E | | |
| Subgroup B-5 | | | 20(1) | 20(1) |
| Salt Atmosphere | 1041 | | | |
| Subgroup B-6 High Temperature Storage Life | 1031 | 200°C | 7(1) (340 hours) | 5(1) (1000 hours) |
| Subgroup B-7 Steady State Operating Life | 1026 | $T_A = 25°C$ $V_{CB} = 25$ V $P_T = 1$ W | 7(1) (340 hours) | 5(1) (1000 hours) |

**TABLE 4 – GROUP C TESTS (2N3866 Family)**

| Inspection or Test | MIL-S-750 Method | Condition | LTPD (Accept No.) | |
|---|---|---|---|---|
| | | | 2N3866JAN | 2N3866JTX/V |
| Subgroup C-1 | | | 10(1) | 10(1) |
| Barometric Pressure | 1001 | | | |
| Thermal Resistance | 3151 | | | |
| Subgroup C-2 Burnout by Pulsing | 3005 | | 10(1) | 10(1) |
| Subgroup C-3 High Temperature Storage Life | 1031 | Extension of B-6 to 1000 hrs | 10(1) | – |
| Subgroup C-4 Steady State Operating Life | 1026 | Extension of B-7 to 1000 hrs | 10(1) | – |

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# HIGH RELIABILITY PROCESSING OF RF TRANSISTORS

### I WAFER PROCESSING

After wafers are processed, they are subjected to Motorola visual inspection specifications then probe tested to determine compliance with Group A specifications upon completion. Probe tests include the following: (1) Class Probe – performed to determine device type and yield; (2) Unit Probe each unit is subjected to Group A electrical tests – rejects are inked. Following the class and unit probe tests, the wafer is scribed and broken.

### II ASSEMBLY

The die are attached to headers and then wire bonded. The following mechanical tests are performed by Quality Control inspectors on a sample basis to ensure assembly process controls.

(1) Wire pull tests

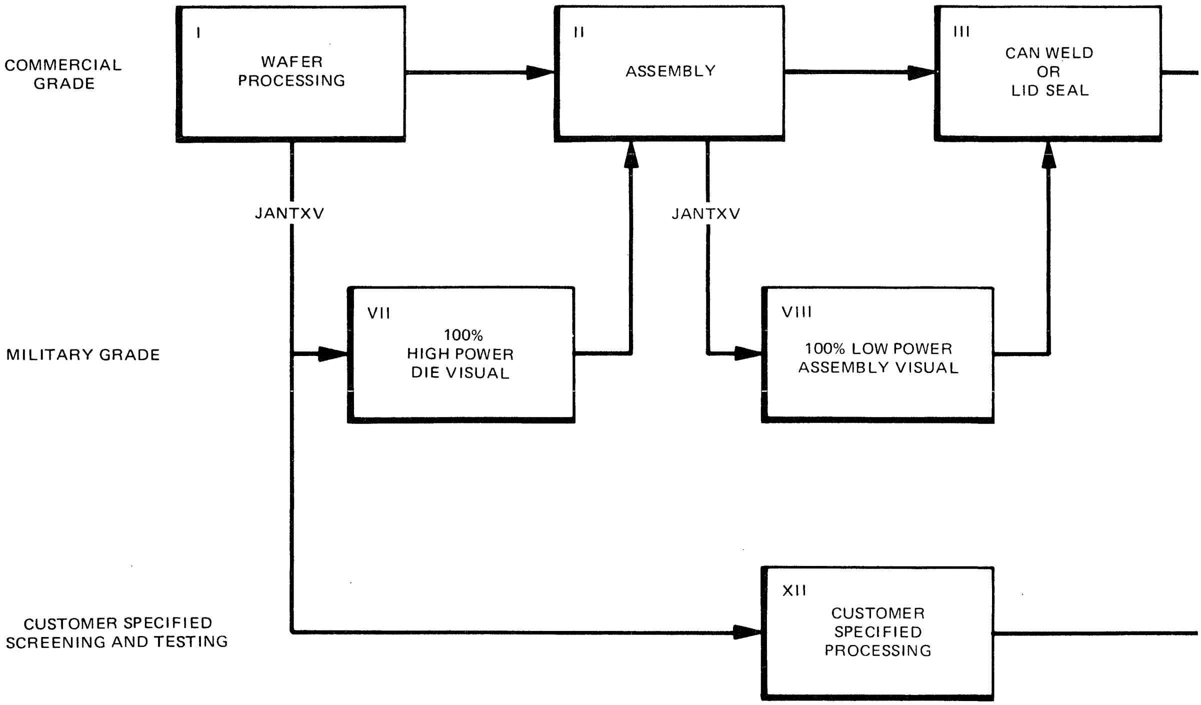
(2) Die push off tests

Units are stored in dry air until ready for capping.

### III CAN WELD OR LID SEAL

Completed headers are loaded into a vacuu chamber for can weld or processed thru a furnace f metal top attachments on ceramic packages wi solder preforms. All devices are subjected to a hi temperature storage (stabilization bake) prior final Group A electrical selection.

## PROCESSING AND QUALITY CONTROL FLOW CHART




### VII 100% HIGH POWER DIE VISUAL

The high power portion of the inspection is performed to assure good die construction and front metal conditions. Individual reject criteria includes the following: Metalization defects such as scratches, voids, corrosion, adherence, bridging and alignment. Poor die construction conditions such as oxide and diffusion faults are also rejected.

### VIII 100% LOW POWER ASSEMBLY VISUAL

The low power visual inspection controls workmanship, i.e., die attachment, internal lead-wire attachment, and package defects. Die attachment inspection includes assuring good adherence, die placement and proper orientation. Internal lead wires must have proper arc and all attachment bonds must be properly placed and in good condition. Package defect inspection includes checking for foreign material, improper construction and cracked glass conditions.

### IV FINAL ELECTRICAL TEST

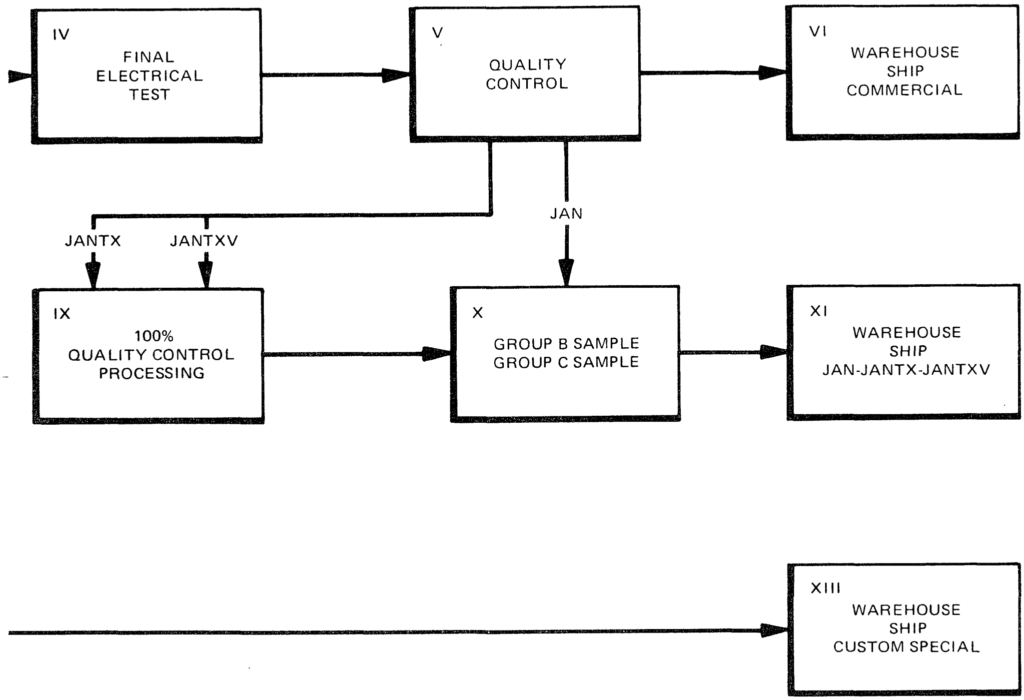
ıpleted units are selected for a Group A electrical Hand screening is performed where necessary. trical fallout units and over-runs are subject to re screening.

### V QUALITY CONTROL

Samples are taken for complete electrical analysis of the lot. Group A and B tests are performed on JAN devices. Group A and B tests and 100% processing are performed on JANTX devices. Some devices also require Group C inspection tests.

### VI WAREHOUSE

Upon completion, the finished product is ready for shipping. Purchase order requirements are carefully checked again prior to shipping. Over-runs are kept for future orders. Warranty tests (Group A) are performed annually on military devices.




### IX 100% QUALITY CONTROL

a. High temperature storage
b. High temperature reverse bias
c. Temperature cycling
d. Thermal shock
e. Hermetic seal
f. Acceleration
g. Read & Record parameters
h. Room temperature burn-in

### X GROUP B AND GROUP C INSPECTION

**Typical Group B Processing (Sample Basis)**

a. Physical dimensions
b. Moisture resistance
c. Terminal strength
d. Hermetic seal
e. Solderability
f. Vibration fatigue
g. 1000 hr. storage life
h. 1000 hr. operating life

**Typical Group C Processing (Sample Basis)**

a. ac parameters
b. Barometric pressure
c. Burn out pulsing
d. Resistance to solvents

rf

semiconductors